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EFFECTS OF POLLUTION ON THE AQUATIC LIFE RESOURCES OF THE SOUTH PLATTE RIVER BASIN

Federal Water Pollution Control Administration
Denver, Colorado

December 1967

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AQUATIC LIFE RESOURCES OF THE
SOUTH PLATTE RIVER BASIN

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South Platte River Basin Project
Denver, Colorado

and
Technical Advisory and Investigations Branch
Cincinnati, Ohio

Federal Water Pollution Control Administration

United States Department of the Interior

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Report (PR-no.)

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Effects of pollution on aquatic life resources of the South Platte River basin in Colorado. (PR-11) Denver, Colorado, and Technical Advisory and Investigations Branch, Cincinnati, Ohio, December 1967. (LC 76-601844) 3/12/71

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FOREWORD

This volume contains the results of biological studies undertaken in the South Platte River Basin during the period of July 1963 through January 1967. A second technical appendix volume containing detailed procedural and analytical information is also available for the professional scientist and engineer. Copies of the technical appendix are available at the following address:

South Platte River Basin Project
Federal Water Pollution Control Administration
U. S. Department of the Interior
1961 Stout Street
Federal Office Building
Denver, Colorado 80202

or

Technical Advisory and Investigations Branch
Federal Water Pollution Control Administration
U. S. Department of the Interior
5555 Ridge Avenue
Cincinnati, Ohio 45213

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SUMMARY OF CONCLUSIONS

GENERAL CONCLUSIONS

1. Biological surveys conducted in the South Platte River Basin, Colorado during the period from 1963 through 1966 showed that large quantities of pollutants were added to the waterways of the Basin; these pollutants debased the waters and adversely affected the aquatic life resources.
2. Organic solids, slime growths, odors, and unsightly appearance of the waters negatively affect the aesthetic values of many streams.
3. Algal growths that are the primary producers of food for aquatic life were eliminated or reduced in many areas. In contrast, in some areas nutrients stimulated an over-production of algae that resulted in undesirable changes in the dissolved oxygen concentrations and the alkalinities of the waters.
4. Pollution eliminated the sensitive clean-water-associated bottom animals and contributed to the development of large populations of pollution-tolerant bottom animals, thus reducing the quantity of available fish food.
5. Pollution contributed to the development of large populations of potential nuisance and disease-vector organisms, such as mosquitos, black flies, and rats.

6. Pollution eliminated fish from many stream reaches and in many other areas changed the composition of the fish community to one of forage and rough fish.
7. In many stream reaches the severity of pollution reduced the stream's assimilative efficiency, thus prolonging the time and distance required for the streams to complete the self-purification process.
8. Beet sugar wastes were the most significant pollutants in the Basin. Damages to aquatic life were detected in 175 miles of the South Platte and its major tributaries.
9. Damage of waterways from mining wastes was widespread in the mountainous portions of the Basin. The causes consisted principally of sedimentation, acids, and heavy metals which varied in effect from subbasin to subbasin. The net product was severe damage to the recreational fisheries by direct toxic action upon the fish and indirect action due to reduced fish-food production.
10. Gravel and sand washeries were widespread through the Basin. Many of them discharged large quantities of sediments which damaged the fisheries of the receiving waters.
11. Pollutional effects were also suspected from food processing wastes, cattle feed lots, and from nutrients in irrigation return waters, although these were not detectable in the already debased waters receiving these wastes.

SPECIFIC CONCLUSIONS

1. In the South Platte River from near Florida Avenue and extending downstream to Platteville (Denver metropolitan area) pollution had destroyed all desirable aquatic life; the only life remaining were the very tolerant organisms such as a few worms and slime growths. Pollution this severe reduces the efficiency of natural assimilation of wastes and is a nuisance and public health hazard due to the attendant problems of odors, revolting aesthetics, and increased populations of rats and mosquitos.
2. In Bear Creek pollution reduced the number of preferred fish-food organisms and during early summer increased the numbers of potential nuisance insects.
3. All but the most tolerant aquatic life had been destroyed in the downstream reaches of Cherry Creek. Periodically wastes reached sufficient concentrations to destroy even the tolerant forms.
4. The upstream reaches of Clear Creek were polluted by mining wastes, principally the heavy metals: zinc, lead and iron. These heavy metals had drastically reduced the valuable recreational fisheries in approximately 30 miles of stream. In the lower reaches (Metropolitan Denver) organic materials were an important pollutant; during the hot summer periods this pollution was sufficient to restrict even the tolerant worms.

5. Sand Creek, intermittent in natural runoff, served as an open sewer that conveyed inadequately treated municipal and industrial waste waters to the South Platte River.

6. Barr Lake was a reservoir of highly polluted water. Long-term septicity during the winter period eliminated animal life. During the summer, abundant nutrients stimulated growths of algae in numbers that would interfere with most water uses. During the summer, these algae produced oxygen which permitted the survival of midge larvae which, along with mosquitos, thrived upon the abundant organic materials in numbers sufficient to be both a nuisance and a public health hazard.

7. St. Vrain Creek was polluted from Longmont downstream to its confluence with the South Platte River. This pollution originated from municipal, beet-sugar processing, animal feed lot, and food processing wastes. During the beet-sugar processing season the combined wastes were strong enough to destroy the tolerant worms, thus seriously reducing the stream's waste assimilative efficiency. During other seasons conditions were improved, but the creek remained sufficiently polluted to inhibit the development of a good fish-food fauna and support increased numbers of nuisance and disease-vector insects.

8. Boulder Creek was severely polluted by municipal wastes from the city of Boulder. Downstream from the city's wastewater outfall the organic waste concentrations adversely affected the

most tolerant of bottom animals. After flowing approximately 15 stream miles (near the confluence with St. Vrain Creek) organic waste concentrations had been reduced to a level that allowed the existence of and nurturing of large numbers of nuisance and disease-vector black flies.

9. Downstream from the Johnstown beet-sugar complex, the Little Thompson River was essentially an open sewer. Aquatic life was restricted principally to slime growths, that were either nurtured on the abundant nutrients, or fed on the large numbers of bacteria. Strong and obnoxious odors were emitted from this highly degraded stream.

10. During autumn and winter, the Big Thompson River contained massive slime growths that were produced from nutrients in the wastes from the beet-sugar mill at Loveland. During other seasons of the year, extensive residual sludge deposits continued to restrict the propagation of fish-food organisms. Throughout the year, the downstream-most 7 miles of the river were continually and severely polluted to the exclusion of all but the most tolerant life by wastes discharged via the Little Thompson River.

11. The Cache la Poudre River was polluted from Fort Collins downstream to its confluence with the South Platte River. Organic

wastes and nutrients from the city of Fort Collins adversely affected the biological community by over-production of algae that produced diurnal fluctuations in dissolved oxygen concentrations, by the biochemical oxygen demand that further reduced dissolved oxygen concentrations, and by the settling of organic solids. The net pollutional effect was the elimination of game fish from much of this reach of river. In autumn and winter the beet-sugar wastes from the Windsor Mill were added to the stream, and these stimulated slimes which destroyed the basic algal food production, fish-food organisms, and the tolerant fish populations that were present during the summer seasons.

12. Wastewaters discharged to the South Platte River from the city of Greeley via the Cache la Poudre increased the nutrients in the waters, which in turn supported increased algal growths and a rise in the populations of nuisance midge and black fly larvae. The quantities of nutrients in the waters are sufficient to produce algal nuisances in the proposed Narrows Reservoir, which is to be built on this reach of river.

13. The beet-sugar mills at Fort Morgan, Sterling, and Ovid seasonally discharged wastewaters that destroyed aquatic life in the South Platte River. Stimulated slime growths and

organic materials were the principal agents that destroyed algae, fish-food organisms, and fish. Sludge deposits were observed throughout the year and had adverse effects upon the aquatic life by reducing the numbers of desirable fish-food organisms and by stimulating increased production of nuisance flies and mosquitos.

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INTRODUCTION

On July 18, 1963 Governor Love of Colorado requested the Secretary of Health, Education, and Welfare to assist the State in determining the quality of waters and sources of pollution in the South Platte River Basin in the State of Colorado and to assist in abating pollution under Section 8 of the Federal Water Pollution Control Act (Public Law 660 as amended).*

The Secretary convened a conference in Denver on October 29, 1963. At this conference it was established that the U. S. Department of Health, Education, and Welfare, in cooperation with the Colorado State Department of Public Health, would initiate a joint investigation and study. This study was to locate the sources of pollution affecting water quality; determine the physical, chemical and biological response of the rivers to pollution; evaluate the sources of pollution with respect to conditions in the river; compute the waste load reductions necessary to obtain desired water quality; and, recommend water quality control and treatment measures needed to effect the desired waste load reduction. Subsequent to the conference, a resident study group, The South Platte River Basin Project, was established by the Department to provide technical assistance for this investigation.

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* Since July 18, 1963, the Federal Water Pollution Control act has been amended by the Water Quality Act of 1965 - (PL 89-234). The provisions of Section 8 of the Federal Water Pollution Act existing in 1963 (PL 87-88) were incorporated in Section 10 of the 1965 Water Quality Act. On May 10, 1966 under provisions of the President's Reorganization Plan No. 2 of 1966 the responsibility for administering the Federal Water Pollution Control Act was transferred from the U. S. Department of Health, Education, and Welfare to the U. S. Department of the Interior.

This report summarizes the results of biological aspects of the Project's investigations in the South Platte River Basin. The report consists of two volumes: 1. The results of biological investigations (this volume) and 2. A Technical Appendix containing detailed procedural information and tabulated data.

DESCRIPTION OF THE BASIN

The South Platte River Basin lies in Northeastern Colorado, Southeastern Wyoming, and Southwestern Nebraska and is part of the headwaters of the Missouri River. This report concerns only the waters within the State of Colorado. Over 80 percent of the Basin's area lies in Colorado and about 95 percent of the volume of the Basin's native surface runoff occurs here (6). In addition to 1,244,000 acre-feet of native surface waters, significant volumes of water are diverted into the Basin from neighboring watersheds - the Colorado River Basin to the West, and the North Platte River Basin to the North. In 1959 about 197,000 acre-feet of water were imported to the Basin, and since then additional imports have been made, notably by the City of Denver. The projected quantity of water available for importation would approximate 600,000 acre-feet annually (1).

The South Platte River is extremely old, dating from before today's Rocky Mountains were formed (2,3). Forty million years ago the river drained a large, flat high altitude plain. South Park at the river's headwaters is a remnant of this plain. A million years ago today's mountains were thrust upward around the river; the river maintaining its position by eroding the new mountains as fast as they rose, thereby cutting a gorge through the Front Range that separates South Park from the flatlands of the lower basin. The ice-age also affected the topography through glacial modification of many of the watershed's mountain valleys. In the high altitudes along the continental divide remnants of these glaciers remain today in Rocky Mountain National Park and at the headwaters of St. Vrain Creek.

The soils of South Park and the great plains are developed on deep alluvial deposits. The mountainous areas have very thin soils or no soil covering the bedrock.

Rainfall is sparse (12-19 inches per annum) in the plains area (1). As air masses move westward over the continental divide moisture in the rapidly rising air condenses, and precipitation occurs. This precipitation may be in excess of fifty inches per annum in some areas of the mountains.

The land's fertility is inverse to the quantity of rainfall. Nutrients in the thin mountain soils have been leached by heavier rainfalls. Low rainfall on the plains has limited the leaching of the soils which are very productive when watered by irrigation.

Two-thirds of Colorado's people live in a thirty-mile-wide strip along the eastern base of the mountains (4). Five of the seven Colorado cities with over 25,000 population are located in this strip and within the South Platte Basin. Here the water originating in the mountains is presently used for irrigation, municipal and industrial water supplies, and recreation.

The mountains are little developed; until recently mining and grazing were the major industries. Today with increased mobility, tourism and recreation oriented to the natural resources of the mountains has become one of the leading Colorado industries.

To the north and east of the populated foot-hill strip, agriculture and agricultural based industries are paramount. These are primarily confined to a "green-belt" along the South Platte River where water from the river and the valley-fill groundwater aquifers is available for irrigation, municipal and industrial needs.

Natural water quality may be divided into two major classes associated with the predominant landforms - mountains and plains.

Thin mountain soils have small groundwater storage capacities; consequently little of the surface water resource is related to groundwater. Most of the stream flow originates as runoff from rainfall or snow-melt. As a result, the waters are soft, containing only small quantities of dissolved salts or nutrients. The heavy vegetation cover prevents rapid runoff and erosion thereby keeping the waters relatively free of suspended materials. Stream gradients are steep (up to 1,000 feet per mile) and stream beds are covered with large rocks; both of which contribute to the water's turbulence. This turbulence increases the aeration, or the dissolving of atmospheric gases and dissipation of gases from organic decomposition, thus aiding the maintenance of desirable dissolved gas characteristics.

The deep soils of the plains cover a large groundwater reservoir, and here larger portions of the stream's waters are related to seepage from groundwater supplies. Dissolved salts and nutrients are leached from the soils by the percolating water, thus increasing hardness and biological productivity when they enter the surface waterways. Groundwater seepage carries little suspended material. The sparse vegetation of the plains permits rapid runoff of water and soil erosion; thus, streams may be very turbid for a short time following rain showers. Stream gradients in the plains are from eight to twenty feet per mile and the channels are developed in alluvial deposits that produce smooth bottoms of soils and gravels, thus turbulence and aeration are reduced compared to the mountain streams.

Pollutants in the mountains originate primarily from recreation and mining. Mountain tourist towns have little wastes of a manufacturing or processing origin. Residential type human wastes are predominant with the quantity fluctuating seasonally in relation to the number of transients occupying the area. Mining wastes are categorized into two major sources: 1) active--from the current mining and processing of ores, and 2) residual--from abandoned mines such as tailing piles and drainage from tunnels.

The eastern plains area waterborne wastes are agriculturally derived. Basic agricultural wastes are exemplified by irrigation return waters, feed-lot drainage, and erosion from poorly managed lands.

In the larger towns industries process agricultural commodities such as sugar, meat, and canned produce. These processing wastes contain organic decomposable wastes, and soils washed from the crops.

In the thirty-mile-wide densely populated area at the foot of the mountains there are more significant waste sources and these wastes are of a more diversified nature than in the mountain or plains areas. Agricultural related wastes are common. Mineral exploitation is primarily of non-metallic resources, especially those related to construction such as sand and gravel processing. In the larger urban areas industrial wastes are varied; examples are wastes from machinery manufacturing, metal finishing, metal fabrication, petrochemical products, paper products, textiles, and leather products. Because of the unequal population distribution, this area has more domestic wastes than the entire remaining area of the Basin.

PREVIOUS WATER QUALITY STUDIES

Following World War II, several studies related to pollution in the South Platte Basin were initiated and reported on. Two volumes are concerned with the quality of surface waters (5,6). One report deals with sources of waste waters (7). Some reports include water quality information as supplemental to other activities or as a part of overall resource planning (1,8). Three publications deal with the effect of waste waters on the surface waters (5,9,10). Most of these reports deal primarily with physical, chemical, and bacteriological characteristics, engineering problems and proposals. Two reports (9,10) contain information on the effects of pollutants on the aquatic biota in limited areas of the Basin.

From 1963 to 1967, twelve reports (references 11 through 22) have been released by the South Platte River Basin Project. This report is prepared in conjunction with activities of this Project and is concerned with the effects of several types of pollutants on the aquatic life resources in most of the South Platte River and its principal tributaries.

OBJECTIVES

The objectives of this report are as follows:

1. Delineate the damages to aquatic life resources by pollution.
2. Delineate the production of undesirable aquatic life stimulated by pollutants
3. Determine the factors causing damage to desirable aquatic life and/or contributing to the production of undesirable aquatic life.
4. Estimate the quantity or type of pollutant removal required to improve the aquatic life resources of the Basin.

AREAS OF STUDY

Not all polluted streams in the South Platte Valley were studied. The major areas of investigation are shown in Figure 1. Relative importance of a waterway, complexity of types of pollutants and effects, climate and seasonal operations, and available manpower were taken into consideration when determining the scope of investigation.

Study emphasis was placed on the populated areas of the Basin. The South Platte River was studied from upstream of Denver downstream to the Nebraska State-line. Permanent tributaries in the thirty-mile-wide "populated belt" along the foot of the mountains were also studied. Duplicate studies at different times were performed when seasonally related industries could appreciably alter the pattern or type of pollutional effects.

Pollution from some activities, such as mining and gravel-washing, has many individual sources that are widely distributed geographically. Time and manpower availability precluded individual investigation of all sites, so selected operations or areas were studied to provide examples of the effects these pollutants may have on the waterways. Studies in the subbasins of Geneva Creek and Mosquito Creek, and the upper reaches of Clear Creek (Figure 1) are examples.

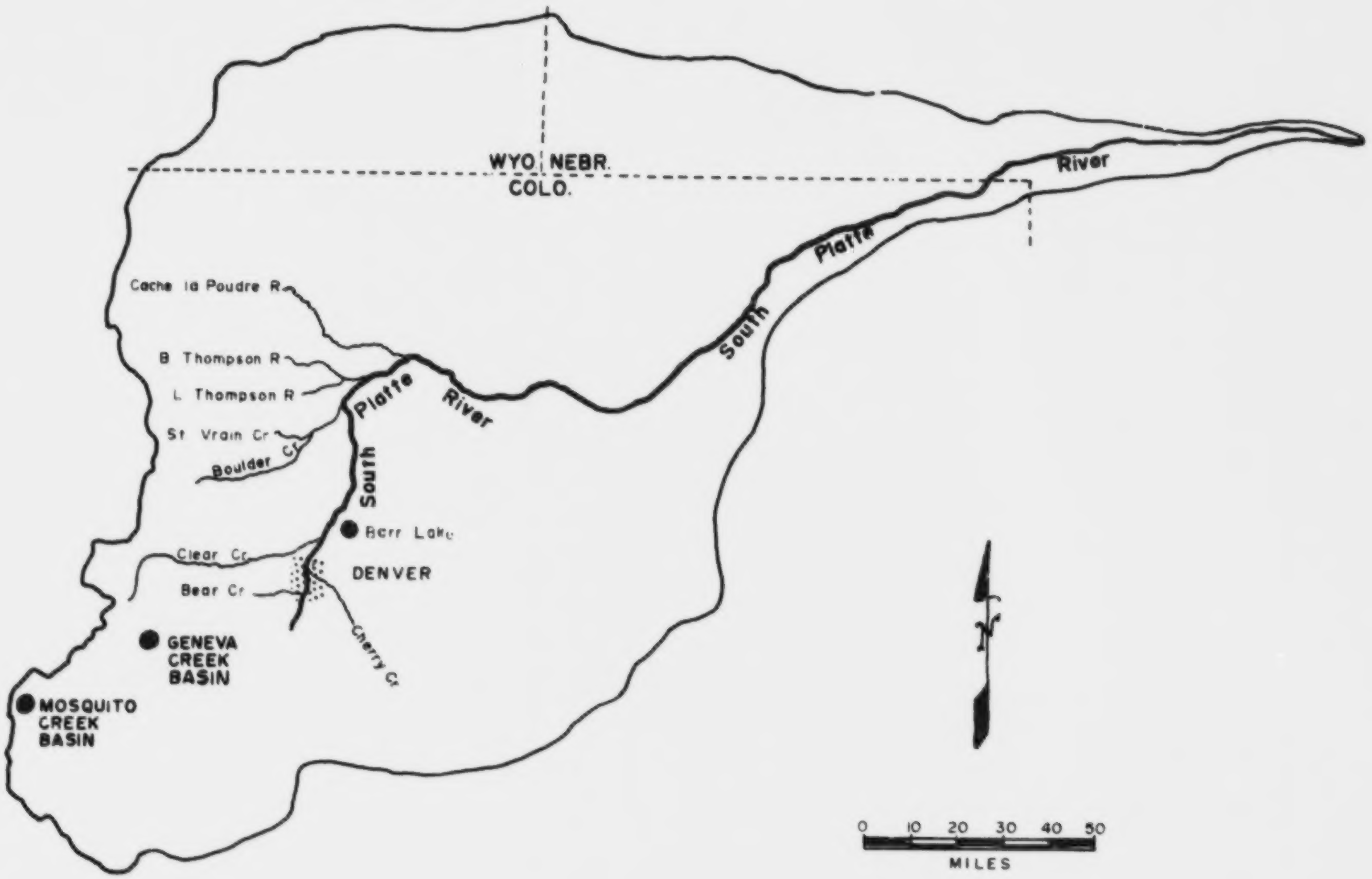
WYO. NEBR.
COLO.
River
Platte
South
Cache la Poudre R.
B. Thompson R.
L. Thompson R.
St. Vrain Cr.
Boulder Cr.
South
Platte
River
Barr Lake
Clear Cr.
Bear Cr.
DENVER
Cherry Cr.
GENEVA CREEK BASIN
MOSQUITO CREEK BASIN
N
0 10 20 30 40 50
MILES

FIGURE I. LOCATION OF STREAMS SAMPLED DURING BIOLOGICAL INVESTIGATIONS IN THE SOUTH PLATTE RIVER BASIN, COLORADO, 1963 - 1966

SURVEY RESULTS

The results of this study are presented in two major units: 1) MUNICIPAL WASTES which is the mixture of domestic and industrial waste waters that are collected, treated, and discharged to waterways by sewerage systems under the jurisdiction of governmental units such as cities and sanitary districts. 2) INDUSTRIAL WASTES consist of specific types of wastes that are related to the type of materials processed by the industry and the wastes are collected, treated, and discharged to the waterways by systems owned by corporations or private individuals.

MUNICIPAL WASTES

These wastes are discussed in relation to their affect on the individual receiving waterway's biota. The effects of municipal wastes are subdivided into geographical areas: The DENVER METROPOLITAN AREA which covers the waters in an area of 30 mile diameter centered on the City of Denver; and the NON-METROPOLITAN AREA which covers the remainder of the Basin or essentially the tributary watersheds of the South Platte River downstream from the St. Vrain Creek watershed, and the mainstem of the South Platte River downstream from the confluence of St. Vrain Creek.

In the DENVER METROPOLITAN AREA, the problem of pollution induced increases in nuisance organism populations is discussed as a unit for all the streams of this area because the problem is widespread throughout this area. In other areas the problems are discussed where they were found and on an individual stream basis.

Denver Metropolitan Area

South Platte River

Wastewaters entering the South Platte River in Denver are of mixed origin. They come from the municipal treatment facilities, industries, cattle holding pens, storm sewers, and via polluted tributaries. The major pollutant is organic solid materials, both suspended and settled. Other pollutants are present, but their effects are masked by the preponderant organic materials.

Excessive quantities of organic wastes, undergoing rapid decomposition, alter the chemical characteristics of the waterway by producing large quantities of sulfides, methane and other products of decomposition, and by reducing the quantity of dissolved oxygen. The settleable solids settle to the stream bottom forming organic rich sludgebeds that "blanket" the original bottom of gravel, rubble, or soil thereby altering the physical environment. These chemical and physical changes are not tolerated by sensitive organisms such as stoneflies, mayflies, and caddisflies,* that are found in unpolluted habitats.

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* All forms of insects are the aquatic stages in the life cycles unless otherwise noted.

Pollution drives these sensitive or clean water organisms from the affected area (if they have migration routes available) or kills them. The surviving tolerant animals, such as sludgeworms, bloodworms, leeches and sewage flies increase in numbers because of a lack of competition from the eliminated forms. Sludgebeds may produce a large increase in numbers because they increase the habitable area and the available food for these "aquatic mature worms." Pollution may become so severe that even these relatively tolerant forms may be reduced in number or even eliminated from the environment (23). Figure 2 illustrates the elimination of sensitive bottom animals and the rapid increase in the population of pollution tolerant organisms as the River enters the City of Denver. A similar survey in August 1964 produced results similar to those in May except for the stations near the confluence of Cherry Creek and at Platteville where the sludgeworm numbers were 38,000 and 19,500 per square foot respectively.

During May and August, from the York Street bridge downstream to Fort Lupton, Colorado, pollution by decomposing organics was severe enough to affect pollution tolerant organisms as evidenced by their reduced numbers (Figure 2). During the May survey, when the flow was being diverted into the Burlington-O'Brian Canal, residual organic solids remained in the channel as extensive odoriferous sludge deposits and were not removed by scouring or decomposition. Flows downstream

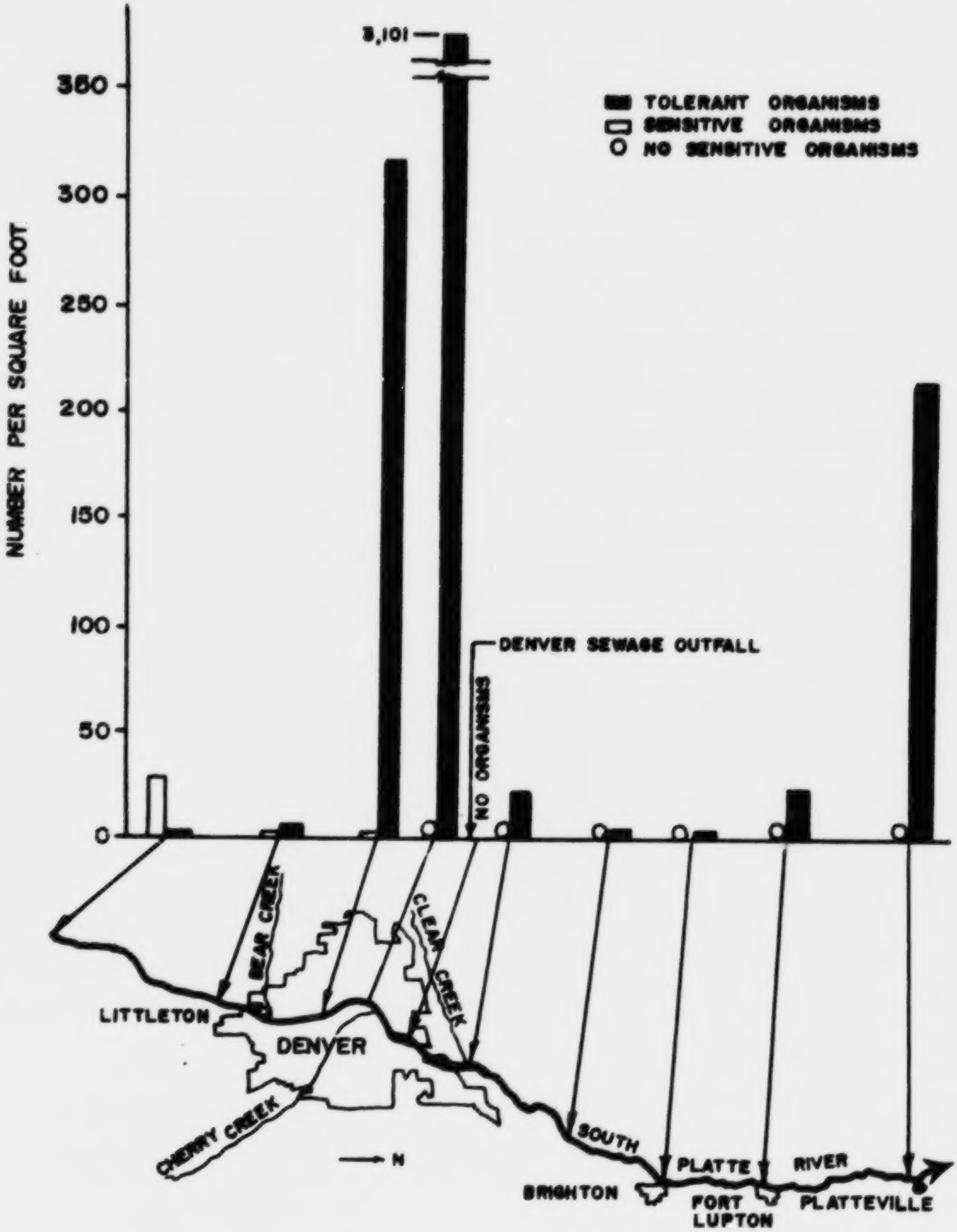

FIGURE 2. POPULATIONS OF BOTTOM ANIMALS, SOUTH PLATTE RIVER, LITTLETON TO PLATTEVILLE, COLORADO, MAY 1964.

from the diversion were low, originating from groundwater seepage and from the small tributaries that were also polluted.

At Franklin Street, the large quantity of decomposing organic material sufficiently lowered water quality so that even pollution tolerant organisms were eliminated. Organic solids were obvious in the River during the May and August surveys; they originated from the Northside Sewage Treatment Plant and other sources. In May and August petroleum oils and animal-vegetable greases also were obvious in the River and its sludge deposits. The bottom in the vicinity of Franklin Street was covered with sludges; in May, a large portion of this sludge, which was estimated to be 45,000 tons wet weight, was obviously rotting cow manure and undoubtedly originated from the cattle holding pens along this reach of River. Deposits of paper fiber were found in May near 88th Avenue.

In May and August downstream from Franklin Street, the pollution tolerant worms were distributed as a thin border along the River's banks. The substrates in the channel, usually occupied by these worms, were covered with extensive growths of filamentous slimes. Aesthetically revolting clumps of slime growths suspended in the water were plainly visible. These slimes contained large numbers of pollution tolerant stalked protozoans, a reflection of the abundance of microscopic organic particles, bacteria, and dissolved nutrients that serve as their food (24).

In areas without sludge deposition, the bottom sands and gravels were stained black from decomposed organic material and possessed a sewage odor. Between Henderson and Brighton, Colorado, the color of the River changed from brown to a dark gray; this is probably because the suspended organic particles had reached a more advanced state of decay.

After flowing forty miles, the River recovered enough to allow large numbers of pollution tolerant sludgeworms and bloodworms to reappear in the bottom sludges at Platteville, Colorado (Figure 2). In August large red patches of sludgeworms (19,500 per square foot) could be seen here on top of the sludge deposits. Filamentous slime growths were less extensive than they were upstream. Within a short distance from Platteville, much of this polluted water is diverted for irrigation and the areas downstream from here are influenced more by pollution from local sources than from the Denver Metropolitan Area.

Bear Creek

Bear Creek is a fertile stream and produces large numbers of bottom organisms (Figures 3 & 9). Downstream from Morrison, Colorado, sewage fertilizes this stream. There was an odor of sewage and suspended fecal and organic particles were visible. The swift and shallow nature of Bear Creek aids in preventing the biota from becoming severely affected by the pollution. During May the increased fertility supported approximately 30 times more organisms than in August at Kipling Street. Additional waste water downstream from Kipling Street reduced the sensitive organism numbers near the confluence of Bear Creek with the South Platte to a level below that found upstream from Morrison. In August, warmer water temperatures accelerated the decomposition of organic materials in the stream and the number of organisms was reduced compared to May. The increased fertility supported more sensitive organisms in May (Figure 3), but it also supported a large number of nuisance organisms such as midges and blackflies (Figure 9).

Cherry Creek

Cherry Creek is a severely polluted stream. Immediately downstream from the Cherry Creek Reservoir, the stream is periodically dry; this does not permit the establishment of a permanent biota. The addition of water from groundwater seepage and storm sewers produces a permanent flow beginning near York Street and extending downstream. Ninety percent of the bottom organisms were pollution tolerant sludgeworms. Sensitive organisms were not found. In August, the sludgeworm population was much reduced from that in May (Figure 4). In spring the discharge of water from Cherry Creek Reservoir added dilution water to the stream, which created a less severely polluted environment for the pollution tolerant sludgeworms as evidenced by their greater numbers. The bottom soils and sludges possessed a sewage odor and contained noticeable quantities of oil. In August an unknown pollutant had killed many pollution tolerant leeches; these were observed drifting downstream near the confluence with the South Platte River.

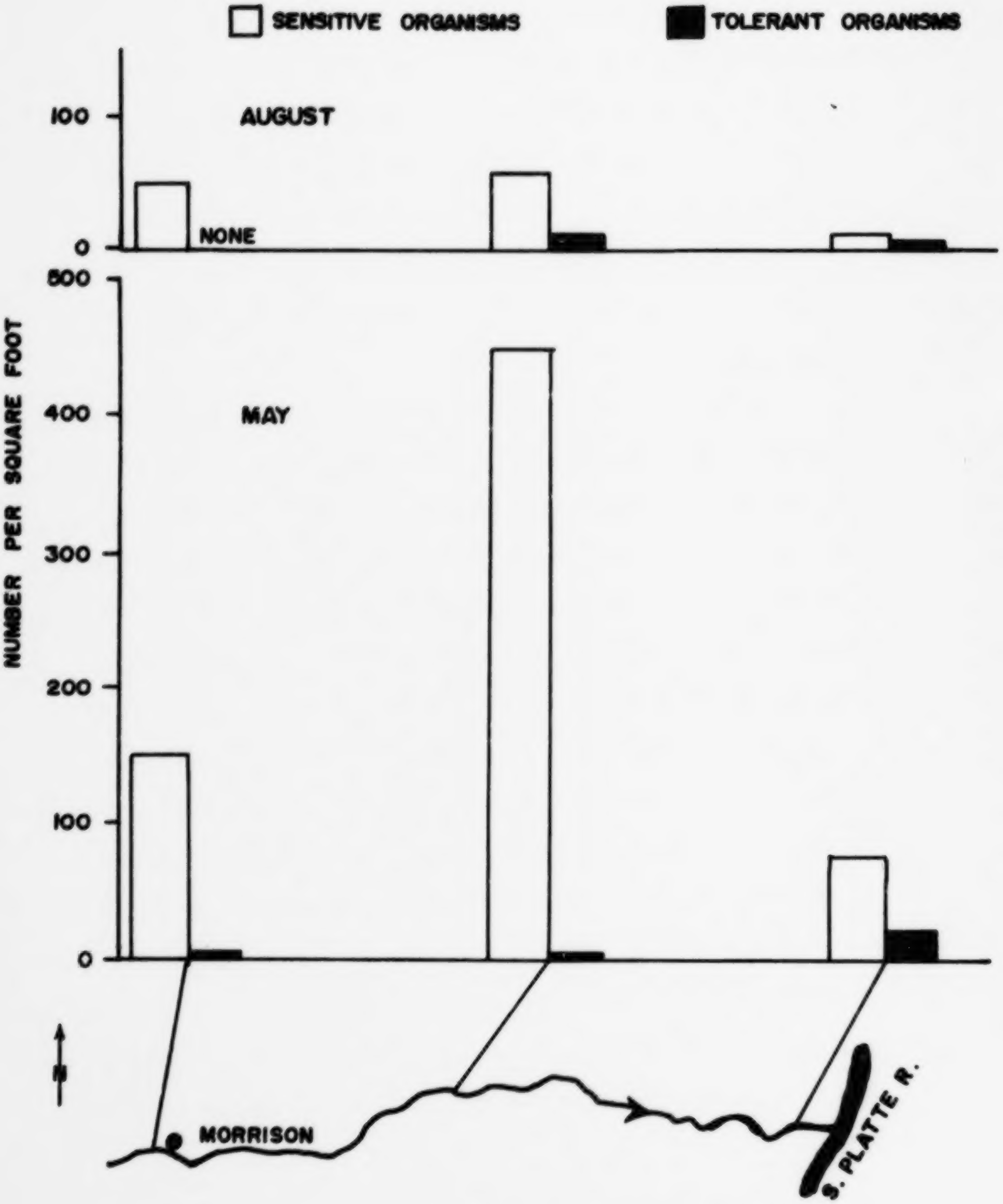

FIGURE 3. POPULATIONS OF BOTTOM ANIMALS IN BEAR CREEK, COLORADO, 1964.

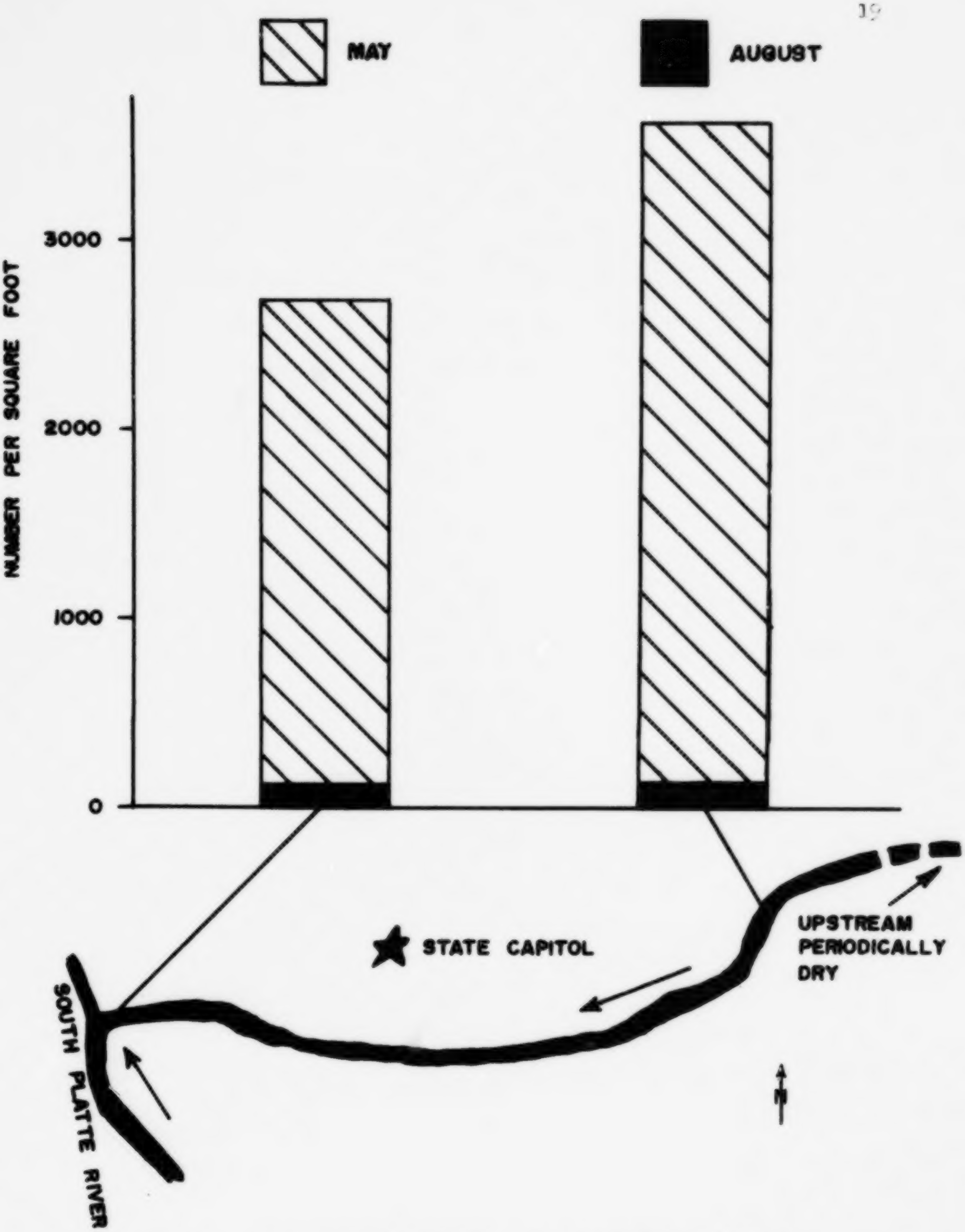

FIGURE 4. SLUDGEWORMS IN CHERRY CREEK, COLORADO, 1964.

Clear Creek

Clear Creek supported extremely low numbers of bottom organisms near Golden, Colorado (Figure 5). This was probably due to a lack of plant life which is the natural basic source of organic food for bottom organisms. The water was very turbid and the lack of plants may have been the result of inhibited light penetration thereby reducing photosynthesis and algal production. Much of the suspended material probably originated from road building activities along the upper reaches of the creek.

At Lakewood, Colorado, the upstream addition of sewage was evidenced by suspended human feces and other organic solids in the water. These organics supported an increased population of organisms (Figure 5), the majority of which were pollution tolerant. Higher populations of sludgeworms were present in May than in August; for example, at the respective times, 10,400 and 150 sludgeworms per square foot were found at Lakewood, Colorado. Near the confluence with the South Platte River, conditions became severe enough to reduce the number of pollution tolerant organisms (Figure 5).

Sand Creek

This is a small stream located on the northside of Denver and it contained water that was primarily wastewater from sewage treatment plants, storm sewers, and industries. The water was gray in color; the bottom was stained gray or black and there was a distinct odor of

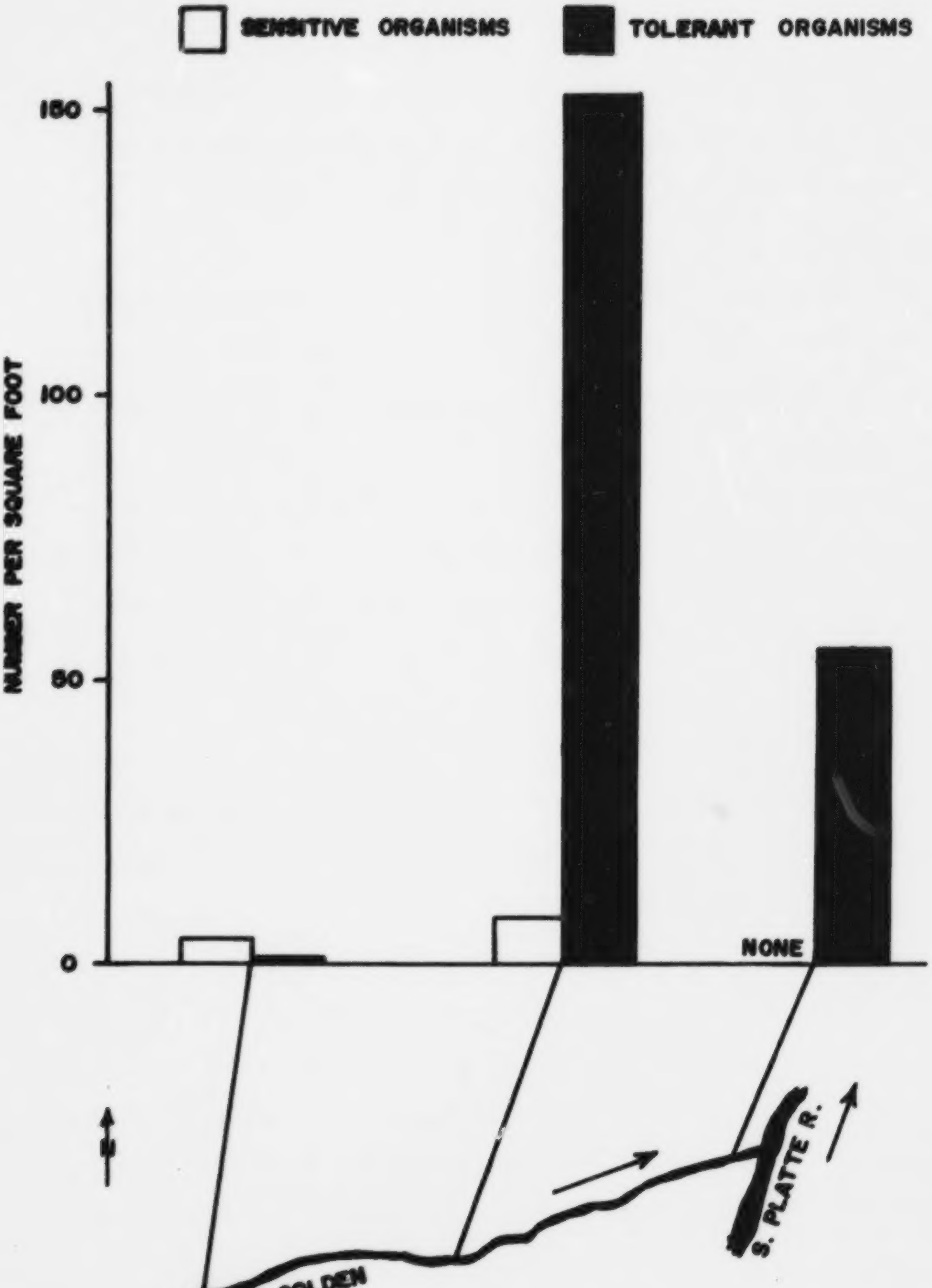

FIGURE 5. POPULATIONS OF BOTTOM ANIMALS IN CLEAR CREEK, COLORADO, AUGUST 1964.

sewage. The biota was extremely sparse and limited to pollution tolerant forms, predominantly sewage fly larvae. Filamentous slime growths occurred on all suitable substrates.

Barr Lake

Barr Lake (Figure 6) is an irrigation reservoir located fourteen miles northeast of Denver. Water to fill the lake is transported via the Burlington-O'Brian Canal and is obtained from the polluted South Platte River, the flow ranging from 13-58 percent (average 35) inadequately treated sewage effluent. The quantity of water in the reservoir fluctuates seasonally as regulated by water storage diversion rights and withdrawal of water for irrigation. Full pool physical characteristics are: 1,870 surface acres, 33,011 acre-feet of volume and a maximum depth of 42 feet (17).

Plankton samples were collected periodically from April through August 1964 (Figure 7). At least 90 percent of the kinds and 99 percent of the total numbers of algae found in Barr Lake have been associated with organically polluted waters (25).

Numbers of algae were lowest in early spring following ice-cover. During late May a large bloom of blue-green algae occurred (800,000 cells per milliliter). Blooms of algae at this season are usually associated with rising water temperatures and a spring turnover of the water mass. Overturn increases suspended materials, dissipates toxic decomposition gases and brings nutrient enriched bottom waters to the

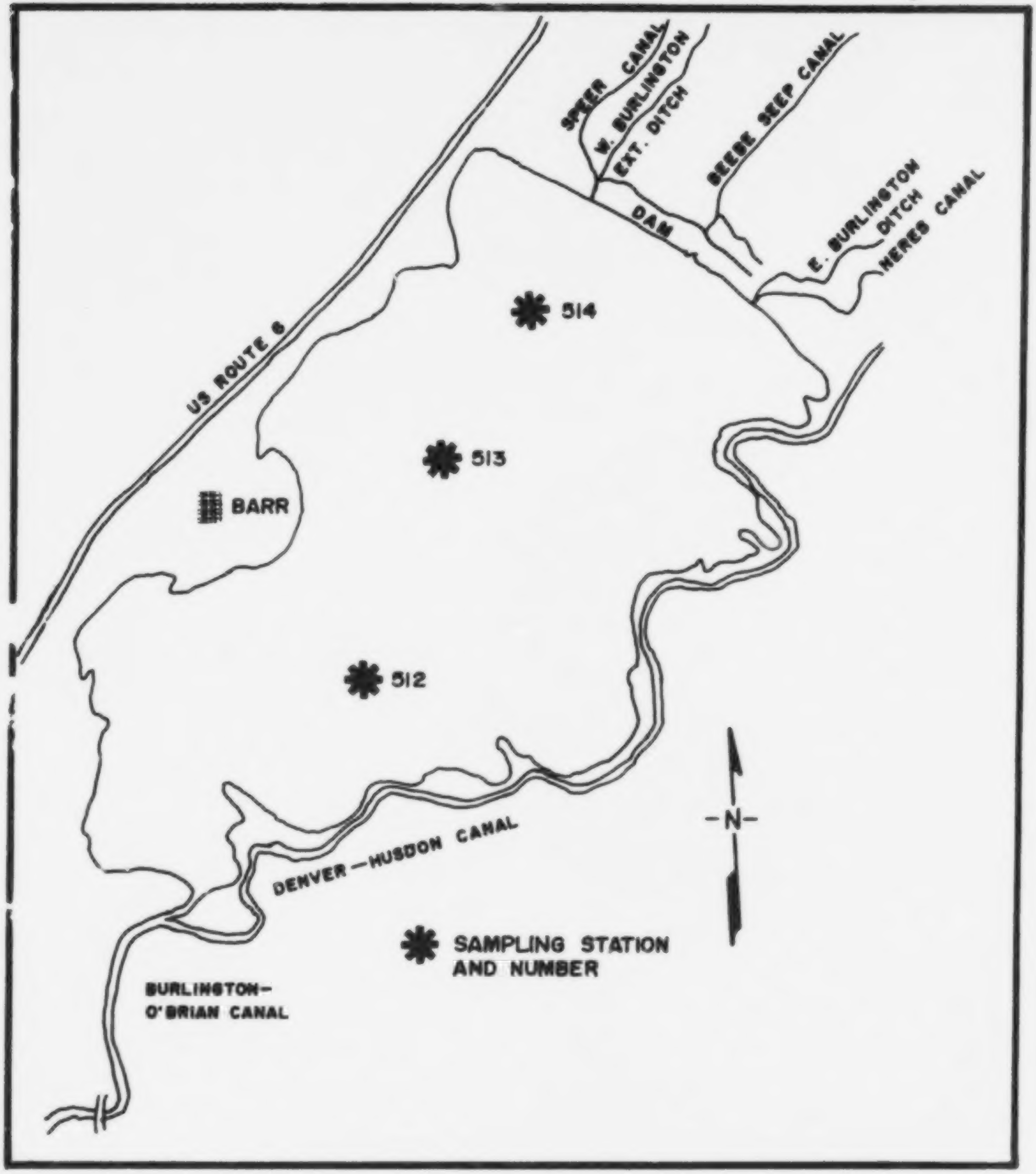
SPEER CANAL
W. BURLINGTON EXT. DITCH
BEEBE SEEP CANAL
E. BURLINGTON DITCH
HERES CANAL
DAM
US ROUTE 6
514
513
BARR
512
N
DENVER—HUSDON CANAL
SAMPLING STATION AND NUMBER
BURLINGTON—O'BRIAN CANAL

FIGURE 6. BARR LAKE, COLORADO, AND PLANKTON SAMPLING STATIONS.

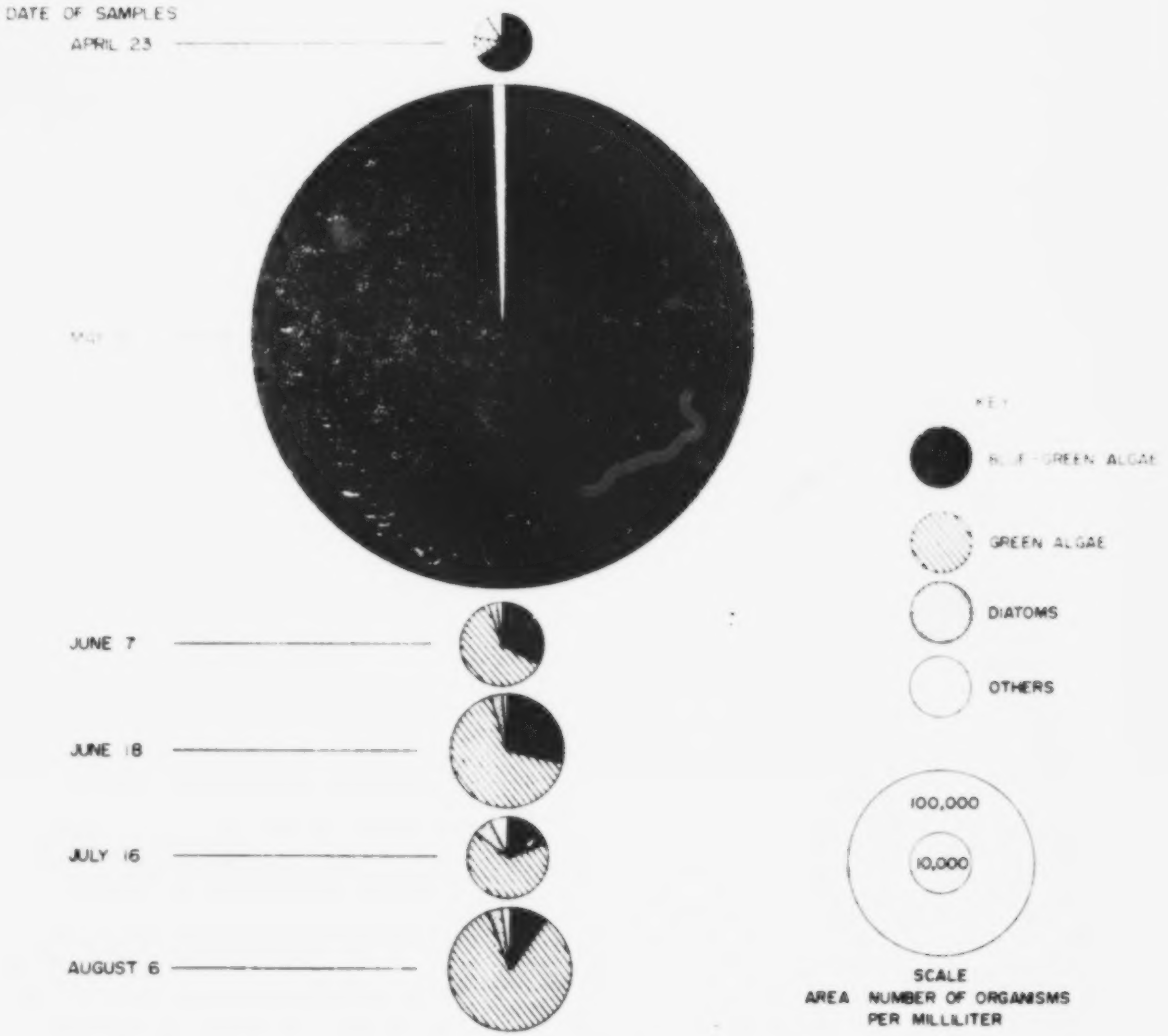

FIGURE 7. SUMMARY OF ANALYSES OF PLANKTON SAMPLES, BARR LAKE, COLORADO, 1964

surface where, in the presence of light, large quantities of algae flourish.

In early June the number of algae was sharply reduced and fluctuated between 15- and 45-thousand cells per milliliter during the summer. Algal counts of this magnitude are dense enough to create nuisances. The use of this algal laden water for domestic, and most industrial and recreational activities, would be prohibited because of the high cost of adequate treatment.

The underlying cause of the dense mass of algae in Barr Lake is related to the presence of nutrients, primarily nitrogen and phosphorus, in the Denver wastewater which is used to fill the impoundment. Increased conventional treatment of this wastewater probably will not effect a significant reduction of the nutrients that are related to algal blooms.

Bottom organisms were studied in May and August, 1964. No bottom organisms were found in May. In August three kinds of midge larvae (bloodworms) and pupae from which midge flies emerge were established on the Lake's bottom. Along with these bloodworms, an occasional predaceous diving beetle and some mosquito larvae were observed along the shore in areas that were protected from wind generated waves.

There was an unexpected lack of several kinds of bottom organisms, such as sludgeworms, leeches, and snails, that are usually found in organically enriched bottom sediments such as those in Barr Lake. While the Lake was being filled with waste water, the decomposing organics caused a depletion of dissolved oxygen. The extended period (from Autumn 1963 until May in 1964) without dissolved oxygen resulted in a kill of the bottom organisms that may have been present. In late May, sufficient oxygen was available in shallow water areas to support tolerant forms. At this time, adult midges flying from other bodies of water successfully deposited eggs on Barr Lake which hatched to produce the bloodworms collected in August. During this period, the isolation of the Lake from other aquatic environments prohibited the ingress of totally aquatic forms such as worms and leeches. Number of collected bloodworms (Figure 8) indicated the success of tolerant midge reproduction. The large numbers per square foot (up to 600) were the result of the abundant organic food in the bottom sediments and the lack of competing and predaceous forms of bottom organisms.

These bloodworms were forms tolerant of low dissolved oxygen concentrations. Figure 8 shows the distribution of bloodworms at various water depths. The highest numbers were found at depths of one through four feet. At the water's edge (0 feet) wave action created an unstable bottom which limited the number of bloodworms. At depths of five through seven feet the population was rapidly reduced compared to the more shallow zones. With increasing depth, chemical conditions

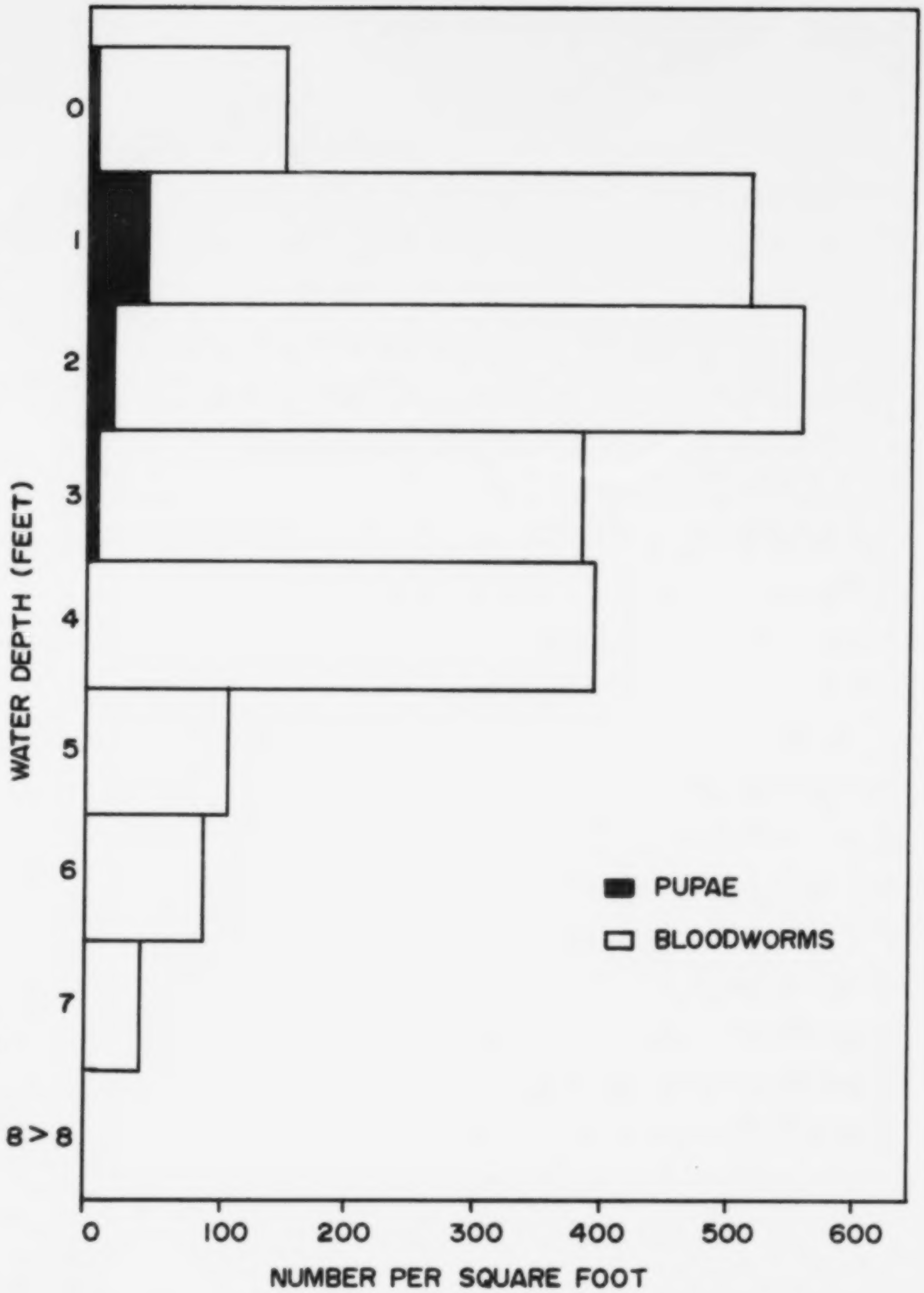

FIGURE 8. DISTRIBUTION OF BLOODWORMS AND PUPAE IN BARR LAKE, COLORADO, AUGUST 1964.

for organisms were obviously becoming more severe at the bottom-water interface as evidenced by ebullient gases rising from organic decomposition in the bottom sediments. At depths of eight feet and greater, gas bubbles were decidedly more prominent and no bottom organisms were found. Pupae were only found in depths of three feet or less because the respiratory system of the midge pupa is less efficient than that of the larvae (bloodworms). Thus, they were restricted from zones of reduced dissolved oxygen.

In late summer and early fall mass emergence of adult midges produces a nuisance. "Midge flies do constitute a nuisance at the lake even now (1964). They were particularly noticeable during late summer and early fall before the first frost. At Horse Creek Reservoir, which is about 20 canal miles beyond Barr Lake (same water supply), tremendously large--almost unbelievable--swarms of midge flies were observed on September 18, 1964." (27). The impact of these nuisances is mitigated by the lack of activity or residential areas in the vicinity of the reservoirs.

A reduction of organic loading to the lake would modify conditions depending on the degree of reduction. A removal of large quantities of organics would eventually reduce the food supply and improve the oxygen resources of the reservoir, thereby permitting the survival of invertebrate and vertebrate competitors throughout the year which would ultimately reduce the number of midges. If the organic loading is reduced, but not sufficiently to allow the development of a diverse animal population, the number of nuisance organisms may increase because of a longer tolerable period for occupancy and/or a greater habitable area as tolerable conditions exist to greater depths. Horse Creek Reservoir may produce larger swarms of midges than Barr Lake, because "From a visual standpoint, the water at Horse Creek Reservoir appears to be of a somewhat better quality than that at Barr Lake..." (27).

Nuisance Organisms

Pollution can create conditions that produce large numbers of nuisance organisms such as midges, black flies, mosquitoes, horse flies and sewage or bee flies. When the more sensitive predators and competitors are suppressed by pollutants and microscopic organic particles that serve as food are added, large numbers of these pests occur. The aquatic larvae transform into noxious adults that bite, or the myriad adults create nuisances by getting into the eyes, ears, nostrils, and mouths of humans and livestock, and may be vectors transmitting diseases to humans and livestock.

Figure 9 illustrates the points where abnormally large numbers of potential pest larvae were found. The areas were all located at the edge of Denver or in the surrounding suburban residential areas. The clean water stream reaches generally had ten or less potential

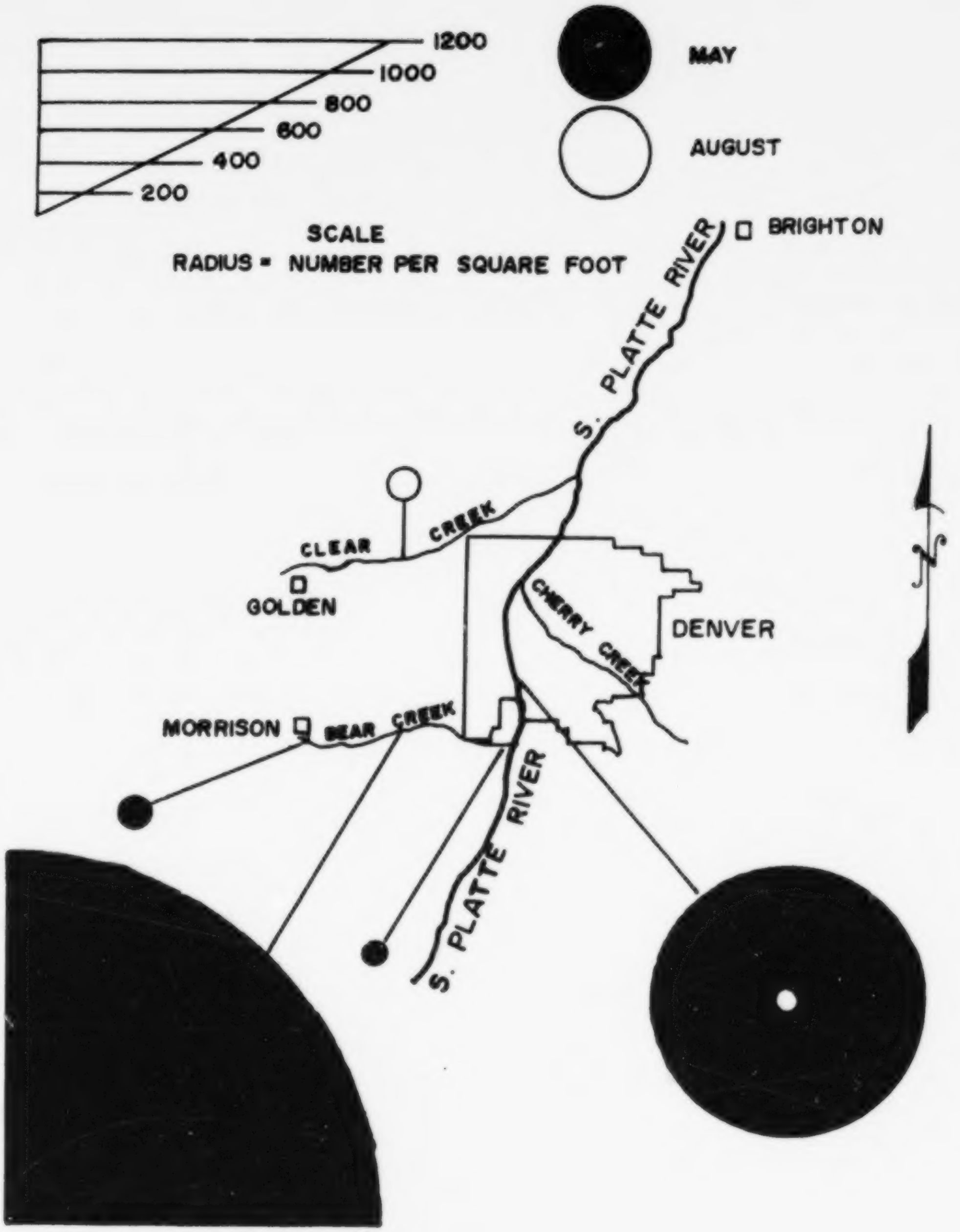
1200
1000
800
600
400
200
SCALE
RADIUS = NUMBER PER SQUARE FOOT
MAY
AUGUST
BRIGHTON
S. PLATTE RIVER
CLEAR CREEK
GOLDEN
CHERRY CREEK
DENVER
N
MORRISON
BEAR CREEK
S. PLATTE RIVER

FIGURE 9. STATIONS WITH 25 OR MORE NUISANCE ORGANISMS (BLACK FLY AND MIDGE LARVAE) PER SQUARE FOOT OF BOTTOM, DENVER METROPOLITAN AREA, 1964.

nuisance organisms per square foot. In Cherry Creek, lower Clear Creek, Sand Creek, and the South Platte River downstream from Florida Avenue, pollution was severe enough to eliminate the semi-tolerant nuisance organisms.

In 1964 the South Platte River Basin Project and the Communicable Disease Center conducted a field study on mosquito production in the North Denver-Barr Lake Area (14). "On the basis of larval collections in the study area, over 93 percent of the total mosquito production recorded occurred in waters associated with heavy organic pollution. While this figure corresponds directly with the percentage of sampling stations located in polluted water, it does indicate the willingness of mosquitoes to breed in these waters. Moreover, members of the genera *Culex* and *Culiseta*, which comprised over 80 percent of this production, are the primary vectors of viral encephalitis. Such high production of these vector mosquitoes constitutes a definite public health hazard particularly in view of the large resident human population concentrated adjacent to the mosquito-producing area. It is significant to note that 83 percent of the mosquito production occurring in the clean water sampling point was of the genus *Aedes*. The *Aedes* mosquito has considerable nuisance impact, but is regarded as having little or no importance as a vector of viral encephalitis.

"Ideal mosquito breeding grounds exist throughout the Basin. Improper irrigation practices create many seeps and standing pools of water in which mosquitoes breed readily. In addition, the many sloughs and backwaters along the river bottoms provide ideal areas for mosquito production. The presence of heavy organic pollution from sewage and industrial wastes in many of these waters enhances the environment for excessive production of those species of mosquitoes associated with the transmission of encephalitis. Encephalitis has occurred sporadically in the Basin with the most recent outbreaks of note occurring in 1957 and 1964."

In conjunction with studies on mosquitoes, investigations related to rat infestations were also undertaken. The report (14) concluded that "Certain areas within the Basin have serious rat infestation problems. The most notable of these is the concentration of a large rat population along the banks of the South Platte River and its tributaries in the northern sector of Metropolitan Denver. Rats are actually semi-aquatic by nature and adapt readily to life along river banks, particularly where brush and trash along the banks provide good cover and harborage. In this case, an excellent food supply is readily available from the heavy load of floating organic pollution present in the South Platte River and its tributaries. The presence of this highly concentrated rat population constitutes a potential plague threat to area citizens."

The overall disease vector problems associated with these large populations of mosquitoes, rats, and flies was deemed a "serious public health hazard" and "...pollution is instrumental in creating and supporting the present high population levels..... Reduction or elimination of present vector populations will best be accomplished through the abatement or elimination of the gross organic pollution now being discharged to receiving waters throughout the Basin."

Incomplete removal of organic materials from the watercourses could reduce the severity of pollution to a level where the semi-tolerant nuisance insects could survive and flourish on the remaining organic material. To reduce the risk of a flourishing nuisance insect population, complete abatement of pollution in the Denver Metropolitan Area is a necessity.

Non-Metropolitan Areas

St. Vrain Creek

This is the first major tributary entering the South Platte River downstream from the Denver Metropolitan Area. Boulder Creek is a major tributary of St. Vrain Creek entering near its confluence (River Mile 17.4) with the South Platte River. From the standpoint of pollution as well as the hydrologic systems the two streams are separate and are discussed as separate entities.

Longmont is the principal source of municipal wastes to St. Vrain Creek. Degradation of waters could be observed, but effects on biota could not be traced for any distance downstream from the Sewage Treatment Plant because within a short distance from the treatment plant discharges, the effects are masked by large quantities of pollutants successively discharged by a cannery, feed-lot, and beet-sugar mill (see, INDUSTRIAL WASTES, pages 54, 129).

Boulder Creek

Boulder Creek was subjected to severe effects of pollution that originated from the City of Boulder. Downstream from the Boulder sewage outfall, the river was murky and dark gray from decomposing organic materials. Large quantities of suspended solids were transported by the waterway. These solids settled to the stream's bottom where they underwent putrefaction.

This inadequately treated waste water had an undesirable effect on the community of bottom organisms. The number of kinds of organisms was reduced through the elimination of the pollution-sensitive forms, such as mayflies and caddisflies (Figure 10). Environmental conditions were so severe that even the tolerant bloodworms and sludgeworms did not develop into the populations of thousands per square foot of stream bottom found in less severe cases of pollution by organic materials that serve as food for these worms. Fifteen stream miles downstream from Boulder, the water quality had improved through the waste assimilation process, polluted water withdrawal for irrigation and recharge of flow through inflow of clean ground water that resulted in a dilution of waste remaining in the waterway. At River Mile 7.3 conditions were ideal for the production of organisms that feed by filtering

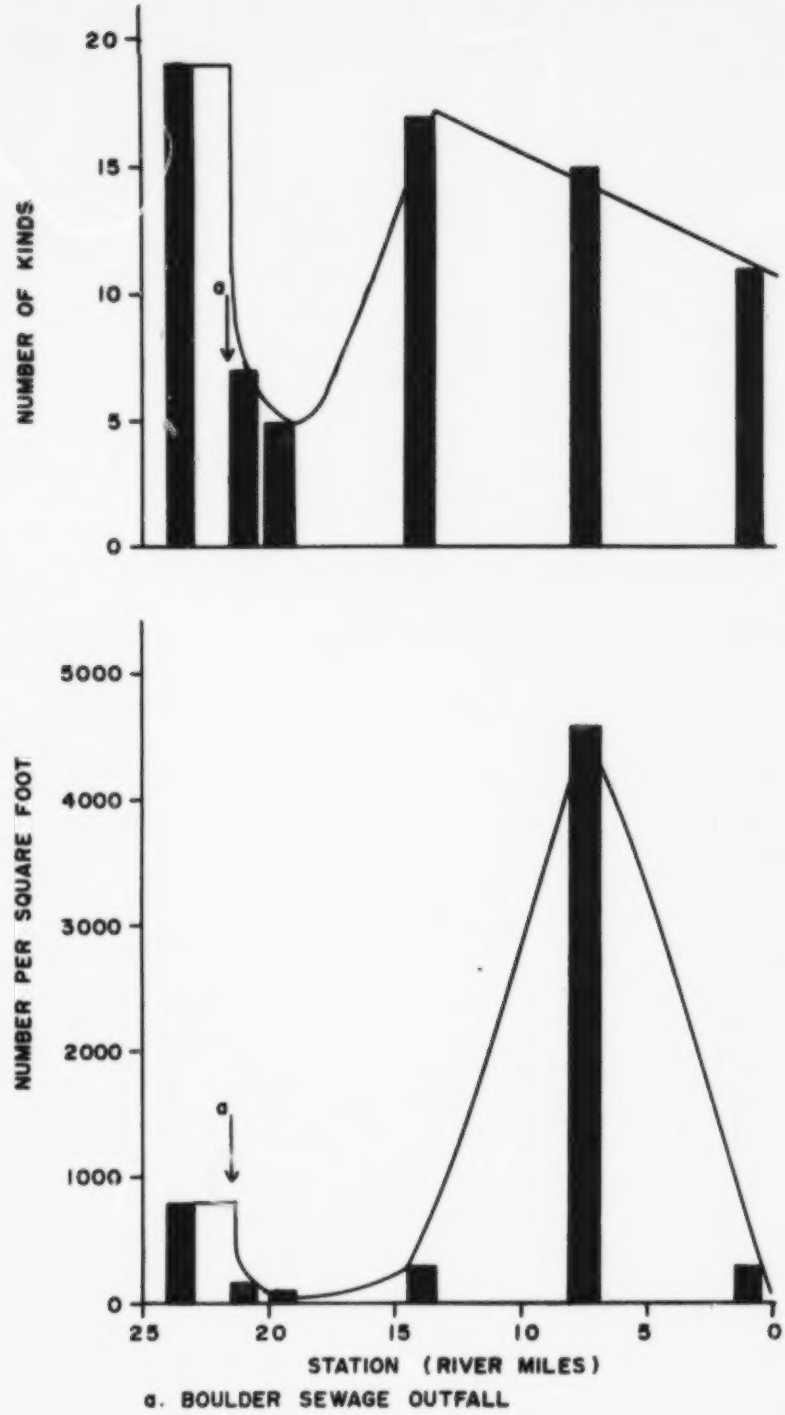

FIGURE 10. EFFECTS OF POLLUTION ON BOTTOM ANIMAL COMMUNITIES IN BOULDER CREEK, COLORADO, AUGUST, 1966.

microscopic organic particles and bacteria from over-passing water. Three thousand, four hundred fifty of the 4,600 animals per square foot were filter-feeding larvae of black flies, that upon emergence as blood-feeding terrestrial adults could be a severe nuisance to humans and livestock on the neighboring farms and ranches.

Big Thompson River

This river has one source of municipal wastes--the City of Loveland. Effects of this waste on the stream biota are not detectable because of the over-riding influence of the large quantities of pollutants discharged by the beet-sugar mill at Loveland.

Cache la Poudre River

This river is the largest tributary of the South Platte River. It receives two major municipal waste loads--Fort Collins and Greeley. In addition, it seasonally receives three large waste loads from beet-sugar mills. Discussion of the effects of the beet-sugar waste load will be deferred to the section on INDUSTRIAL WASTES.

The City of Greeley discharges its wastes near the terminus of the Cache la Poudre River, affecting 5.3 miles of the river before it enters the South Platte River.

The discharges of inadequately treated waste waters by the City of Fort Collins adversely affects a much larger reach of the river. Adverse effects on the stream originate principally as two waste-water constituents: 1) organic material, and 2) nutrients. In the early

1960's the inadequate Fort Collins municipal sewage treatment plant was removing less than 70 percent of the decomposing organic material (biochemical oxygen demand, BOD) (11), and the population of the city and Colorado State University has continued to grow. Bypassing of untreated sewage occurs; suspended fecal material and chopped garbage were seen in the river--a sign of the presence of raw, untreated sewage. The decomposition of organic materials reduces the concentration of dissolved oxygen, a necessity for desirable aquatic life.

Large quantities of nutrients are also discharged in municipal wastes. These nutrients can stimulate the growth of large quantities of aquatic plants. During daylight hours the photosynthesis of plants produces a surplus of dissolved oxygen that is released to the water--an asset in the oxygen balance of the waterway. But at night the lack of light stops the photosynthetic process, and the continuous plant respiratory process draws oxygen from the waters--a debit in the oxygen balance of the waterway. As a result, diurnal oxygen fluctuations occur with high concentrations during the day and low concentrations in the early morning hours of darkness.

Downstream from the municipal waste sources, substantial increases in nitrogen and phosphorus plant fertilizers were found in the Cache la Poudre River during August 1966 (Figure 11). Data analyses indicate that neither phosphorus nor nitrogen was a limiting factor

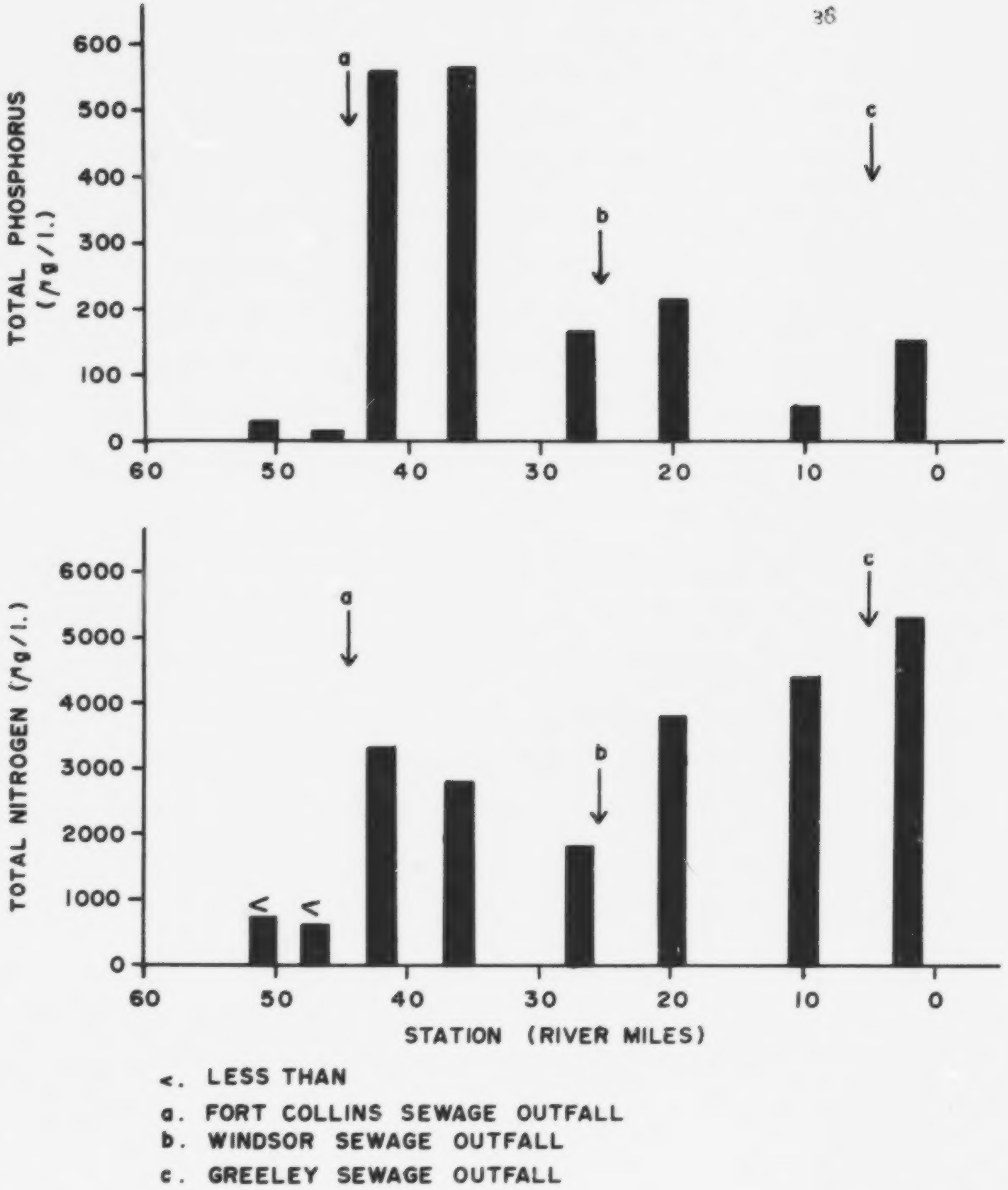

FIGURE 11. MEAN DAILY NITROGEN AND PHOSPHORUS CONCENTRATION (micrograms/liter), CACHE la POUDRE RIVER, COLORADO, AUGUST 1966.

that governed the quantity of algae present. In fact, phosphorus and nitrogen concentrations were much higher than those levels generally believed to be necessary for algal growths (28). The general trend was, as both nitrogen and phosphorus increased, the production of attached algal growths increased also (Figure 12).

Chlorophyll is the key catalyst (enzyme) in the photosynthetic process of plants. The quantity present is indicative of the standing crop of plant material present, and the rate of growth on the glass slides is a function of the rates of production of plant material, and of photosynthetic activity.

Figure 13 illustrates the effects of the attached algae, measured as chlorophyll, upon the daily maximum and minimum dissolved oxygen concentrations. During day-light hours the stream becomes supersaturated with oxygen. A maximum concentration of slightly over 12 mg/l is reached in the stream and then the additional oxygen produced is lost by diffusion to the atmosphere. At night, the plant's respiration reduces the dissolved oxygen concentrations below the level of saturation; the amount of nighttime reduction increases with an increasing quantity of plants.

Evaluation of diurnal alkalinity values also demonstrates the effect of aquatic plants on the chemical characteristics of the waterway. Alkalinity, in quantity and form, is governed by dissolved carbon dioxide (carbonic acid). Photosynthesis converts the carbon dioxide

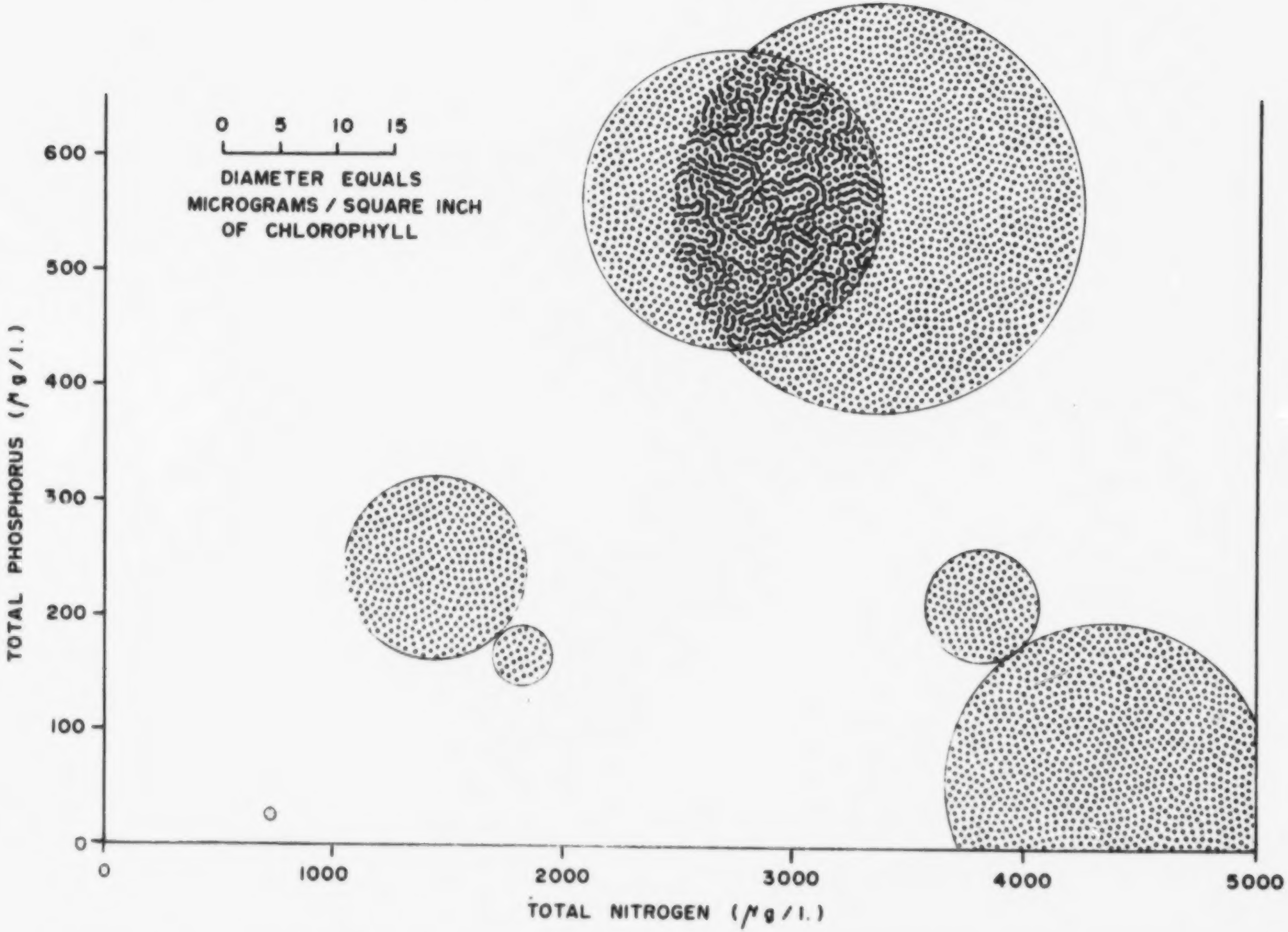

FIGURE 12. EFFECTS OF INCREASING NUTRIENTS, NITROGEN AND PHOSPHORUS, ON ATTACHED ALGAL PRODUCTION (AS CHLOROPHYLL), CACHE la POUDRE RIVER, COLORADO, AUGUST 1966.

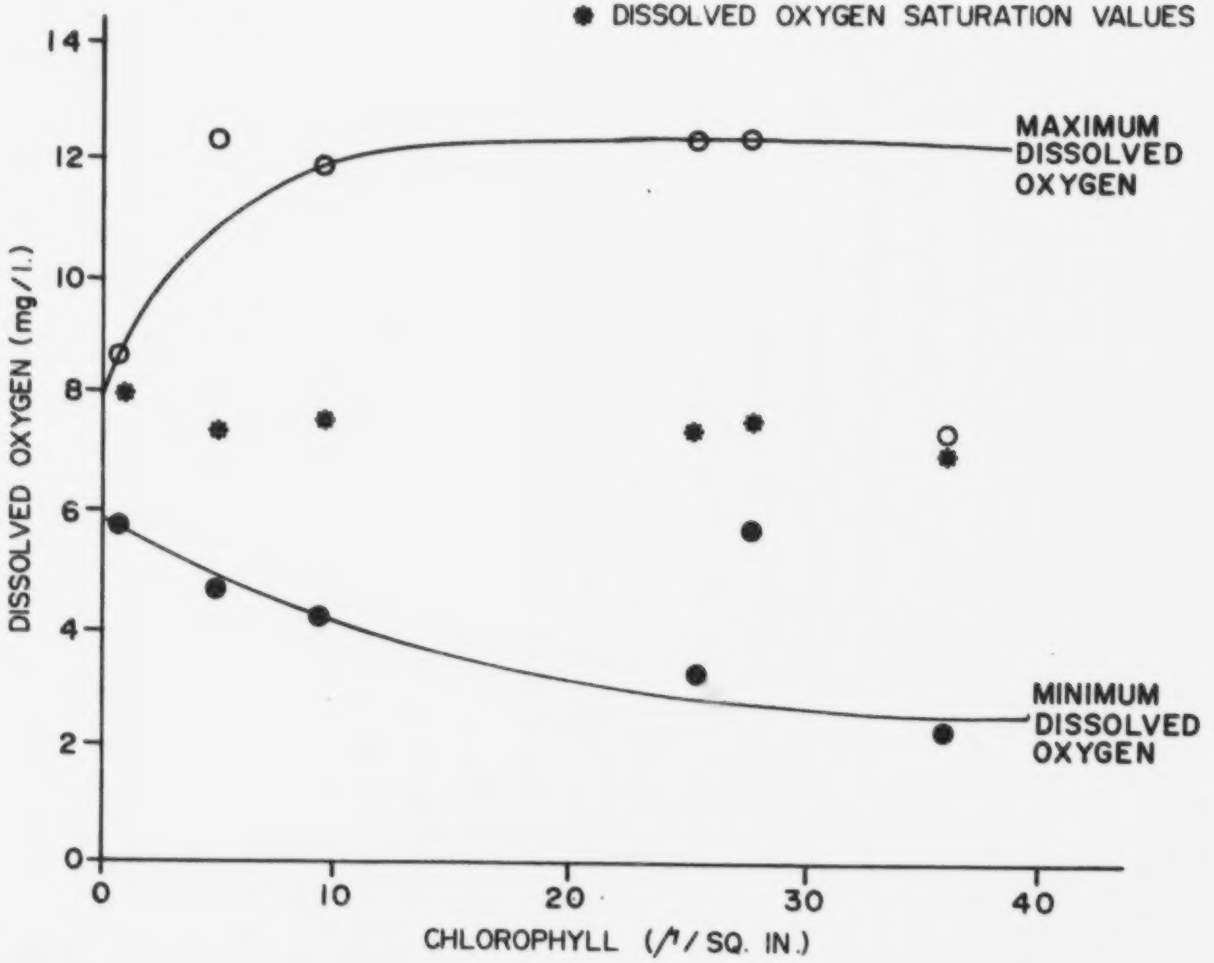

FIGURE 13. EFFECTS OF CHLOROPHYLL (PHOTOSYNTHESIS AND RESPIRATION OF PLANTS) ON THE DAILY MAXIMUM AND MINIMUM DISSOLVED OXYGEN CONCENTRATIONS, CACHE la POUDRE RIVER, AUGUST 1966.

to sugars, and oxygen that is released to the water. As the carbon dioxide is used for photosynthesis, the dissolved fraction is continuously reduced. The calcium bicarbonate is converted to carbonates, thus releasing additional carbon dioxide for photosynthesis. The solubility of carbonates is less than the bicarbonates, and precipitation as marl may occur. The net result of high rates of plant photosynthesis is a reduction in the total alkalinity because of the marl precipitation, and the formation of (or increase in) the carbonate form of alkalinity, and an increase in pH values. Figure 14 illustrates these alkalinity changes in the Cache la Poudre River. In areas where large changes occurred between the day and night concentrations, the total alkalinity was reduced, and the carbonate form appeared as a fraction of the alkalinity during the daylight hours; at night the carbon dioxide was released by the respiring plants, reacted with the carbonates converting them to bicarbonates and the total alkalinities were higher than when compared to the daytime period. Besides being indicative of the photosynthetic and respiratory activity of the plants in a waterway, this decrease in alkalinity reduces the water's buffering capacity, and thus its capability to neutralize surges in wastes. This is especially true for those wastes that are alkaline in nature because the stream's acidic portion (carbonic acid and bicarbonates) of the buffering system is nearly exhausted and pH values are already high (carbonate alkalinity does not occur at pH levels of less than 8.3).

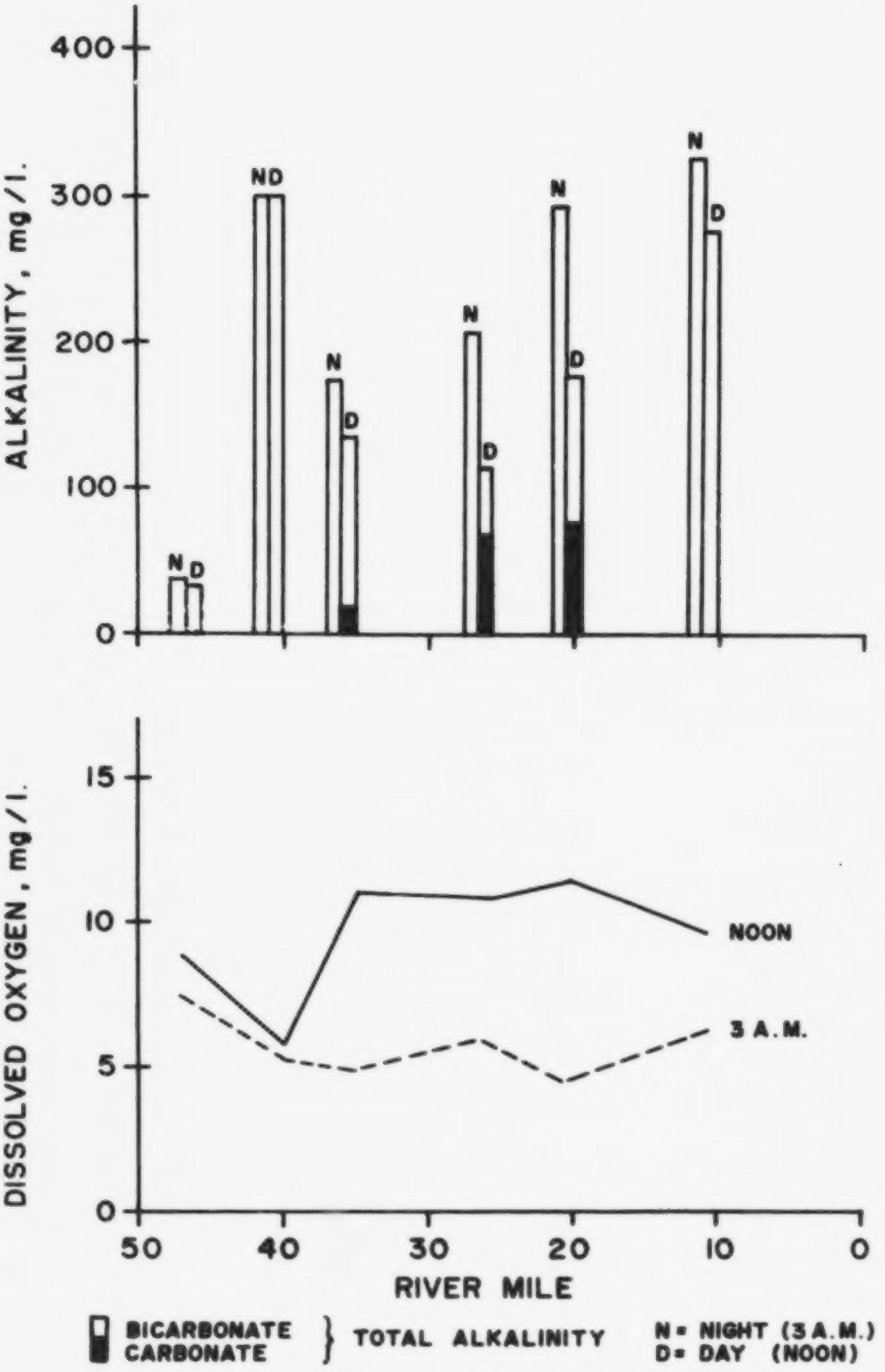

FIGURE 14. EFFECT OF PHOTOSYNTHETIC OXYGEN PRODUCTION ON THE BICARBONATE AND CARBONATE ALKALINITIES IN THE CACHE la POUDRE RIVER, COLORADO, AUGUST 1966.

The net effect of these diurnal oxygen fluctuations is the creation of an environment that is not suitable for the propagation of desirable forms of fish. Five mg/l of dissolved oxygen is the generally prescribed lower permissible limit for maintaining a "good fish faunae" (29). Figure 15 summarizes the diurnal dissolved oxygen fluctuations and the fish fauna observed at sampling points along the Cache la Poudre River. If the nighttime dissolved oxygen concentrations were less than 5 mg/l, regardless of the concentration at any other time of day, game fish (excluding bullheads*) were not present in the fish samples. This dissolved oxygen level is quite critical. In a nation-wide survey (29) over 96 percent of the stations sampled that contained "good, mixed fish fauna" had over 5 mg/l of dissolved oxygen. No stations sampled in the Missouri River Basin were an exception, including 7 stations within the South Platte Basin.

In the reach from Fort Collins to Windsor, the wastes from the City of Fort Collins were the prime pollutant. The stream productivity is increased as measured by algal growths, bottom animals, and fish; but this increased production is diverted into less desirable forms by adverse effects of the pollution. In summer, the number of bottom animals increased by 300 percent below Fort Collins compared to upstream

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* Bullheads are a game fish in Colorado, and their capture is regulated by State fishing regulations.

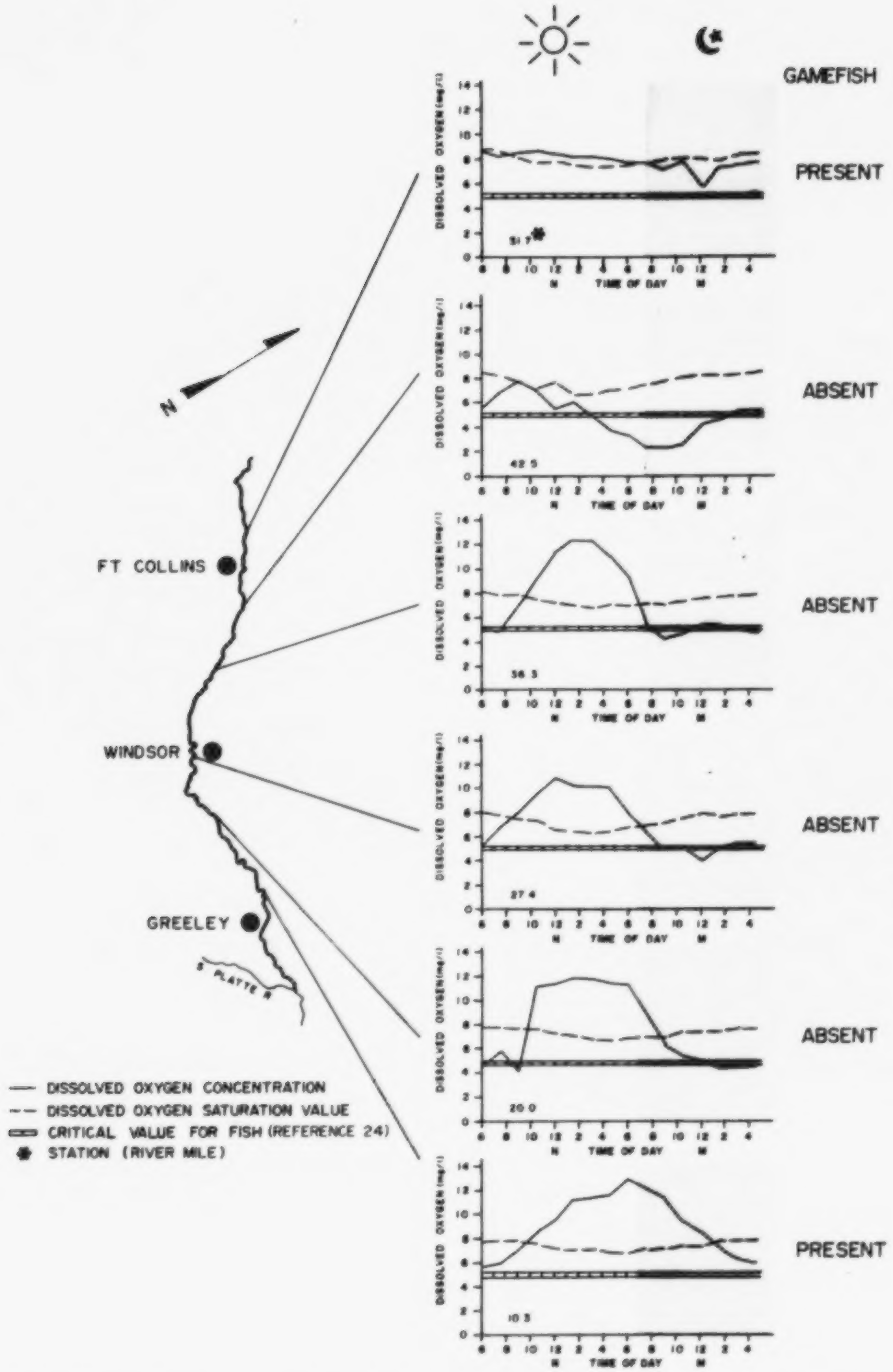


FIGURE 15. DIURNAL OXYGEN CONCENTRATIONS AND GAMEFISH, CACHE la POUDRE RIVER, COLORADO, AUGUST 1966.

from the city. Midge larvae and worms were the principal forms of animals that increased (about 1,300 percent more downstream from Fort Collins than upstream from the city). This increase was principally a result of increased food for these herbivorous and detrital feeding animals. The total weight of fish captured in test trap nets was 50 percent greater downstream from the city than upstream. Eighty percent of this increase may be attributed to carp, because of their rooting feeding habits they are more capable than many species of preying on the burrowing worms and the midge larvae contained within algal mats and detrital deposits.

In September 1966 an extensive fish kill occurred immediately downstream from the City of Fort Collins. Fish sampling in November revealed only 2 species of suckers in this reach, compared to 8 species of fish in the samples from August. The suckers captured in November also weighed on the average 50 percent more than those in the August samples. The large suckers probably had an advantage in mobility over smaller fish, and therefore had an advantage in immigrating back into this reach of river after environmental conditions improved following the fish kill.

South Platte River

Greeley waste waters are discharged to the Cache la Poudre River 5.3 miles above its confluence with the South Platte River. Effects of this waste on the biota in the Cache la Poudre River were not readily discernible because of the over-riding influence on the biota by massive year-round sludge deposits, most of which are attributable to upstream beet-sugar waste discharges. During the summer months the city's wastewater exerted a distinct influence on the South Platte River. Much of the effect can be attributed to the nutrients in the wastewater discharged to the South Platte.

The quantity of phosphorus increased 150 percent in the South Platte River downstream from the confluence of the Cache la Poudre River. As a consequence of the fertilization, the quantity and growth rate of attached algae, measured as chlorophyll, also increased (Figure 16). In turn, the insect population responded to the increased algal food. In the denser algal mats near the fertilizer source, the insect population was predominantly midge larvae that prefer the habitat of thick, filamentous algal growths, in which they can burrow, and graze. In areas with less dense algal growths, the black fly larvae increased in relative number to the midge larvae. These flies required a firmer substrate for attachment by their posterior suckers than is provided by filamentous algae, and the thickness of the algal growths upon the substrate attachment must be thin enough to permit the larvae to extend their anterior filter-feeding apparatus up into the bypassing free-flowing water.

The increase in black fly larvae is also related to an increase in food. Erosion of algal material from its site of attached growth

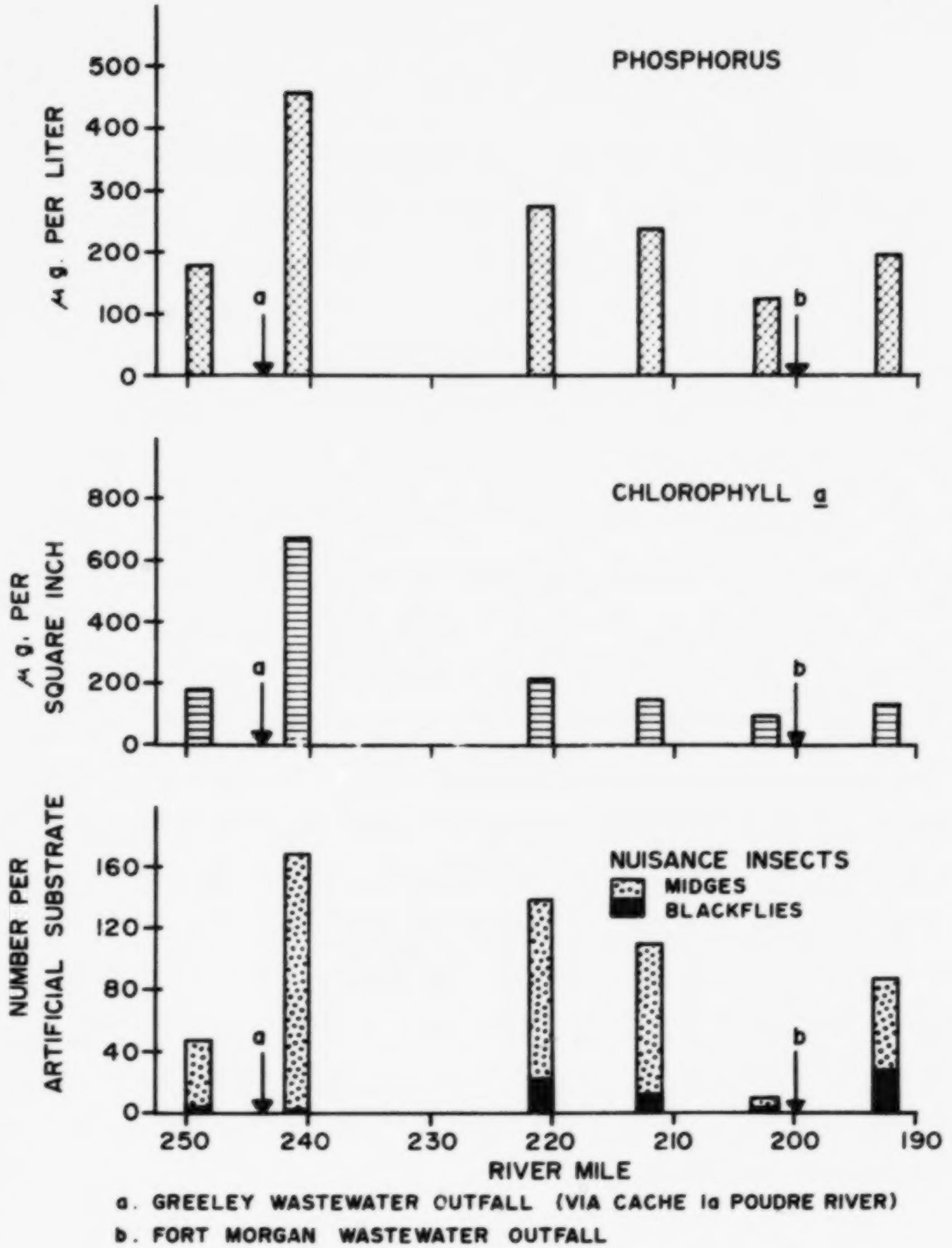


FIGURE 16. PHOSPHORUS, ATTACHED ALGAE (AS CHLOROPHYLL a) AND NUISANCE INSECTS, SOUTH PLATTE RIVER, SEPTEMBER, 1964.

is a primary source of food that is captured from the over-flowing water by these larvae. More algae growing upstream from a sampling site produce more drifting food for animals at the sampling site.

The nutrient phosphorus is assimilated by the waterway at a predictable rate (based on the miles the water has traveled) (Figure 17). The production (growth rate) of algae is also reduced at a relatively steady rate with increasing distance from the source. The rate of reduction of algal production is greater than the rate of phosphorus reduction, indicating that some factor other than phosphorus is limiting the plant production rate. This would be expected, because the phosphorus concentrations are significantly higher than any concentration that has been reported as limiting growth rates (28).

The uptake of nutrients from the water is of special interest in this reach of the South Platte River because of the proposed mainstream Narrows Dam and Reservoir to be constructed here. The impoundment would flood the reach of river from approximately river mile 219 to river mile 202. The projection (Figure 17) indicates that the phosphorus concentration in water entering the reservoir would be in excess of 250 μg/l. This concentration is nearly ten-fold the concentrations at which problems may be expected in lakes related to the excess production of algae that in turn interfere with water uses such as recreation, fishing and domestic and industrial water supplies. The Bureau of Reclamation, in its economic cost-benefit studies for the reservoir (30),

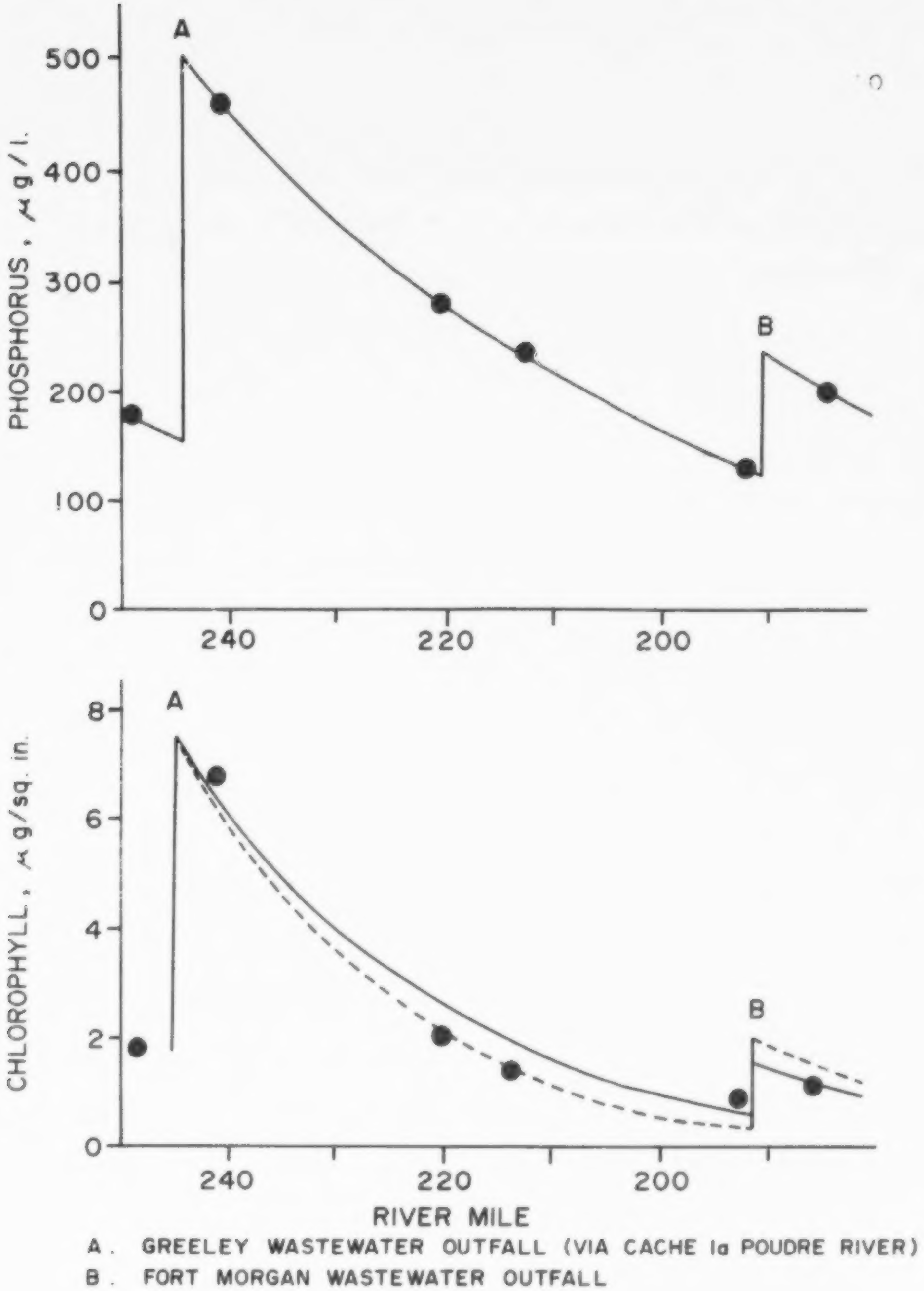


FIGURE 17. THE RATE (k,-.011) OF PHOSPHORUS ASSIMILATION, AND RATE (solid line—k,-.04; dashed line-k,-.043) OF REDUCTION OF ALGAL PRODUCTION, SOUTH PLATTE RIVER, SEPTEMBER 1964.

has estimated the per annum values for water uses that could be affected as follows:

Fish and Wildlife Enhancement	$292,700 per annum
Recreation	$790,000 per annum

This over-one-million-dollar-per-annum value is 34 percent of the total annual benefits of the reservoir. Interference with these valuable water uses could be a very costly proposition.

The analog computer projection (Figure 17) indicates how closely the increase in phosphorus content is related to the quantity of wastewaters entering the river. The ratio of concentration increase between the cities of Greeley and Fort Morgan is 3.2, and the ratio between the sewered population of these cities is 3.25 (11).

The effects of municipal wastes were also observed at the Colorado-Nebraska State-line. Here the origin of wastes was the Julesburg, Colorado, sewage system. The river bottom contained extensive sludge deposits and the flowing waters were gray with suspended organic materials. In September, 1963, compared to upstream from Julesburg there was a 45 percent reduction in the variety of bottom organisms that inhabited the area near the Stateline. With the exception of one specimen of mayfly, the surviving forms were all tolerant midge larvae or worms. There was also a 93 percent reduction in the total number of organisms thus indicating that environmental conditions were severe enough to restrict the utilization of the organic materials as food by even the tolerant forms of bottom animals.

Increases in nutrients and algal production downstream from municipal wastewater sources also were observed during summer at other points in the Basin, such as the reach of the South Platte River downstream from Sterling, St. Vrain Creek, and the Big Thompson River. In many of these areas, the effects were not as obvious because of the influence of other components of pollution, industrial waste sources, and residual effects of seasonal pollutants.

Summary of Municipal Wastes Effects

In summary, the municipal waste waters contain direct and indirect acting pollutional components. The direct acting components, such as decomposing organic material and settleable solids, are the predominant pollutional factor in the severely polluted areas such as in Metropolitan Denver. In less severely polluted streams, such as the Cache la Poudre River downstream from Fort Collins and the South Platte River near Greeley, the indirect acting components may lead to the development of in-stream conditions that in themselves, or in combination with direct acting components, also adversely affect the aquatic life resources of the waterway. Thus, for preservation of the waterway resources, all the wastewater components need to be considered. For aquatic life preservation, the pollutional components first considered for removal must be the direct acting oxygen consuming organic materials and the settleable solids. In planning for their removal, provision must also be made for additional treatment to remove the indirect acting pollutants. In some instances the additional treatment facilities may be readily incorporated in future construction. In other areas, the need may not be immediately apparent, or can be prolonged until increased population increases the quantities to a harmful level. All planning should provide for increased future treatment by the use of treatment plant designs that readily allow both the expansion of the plant and the incorporation of additional treatment methodologies, as needed.

INDUSTRIAL WASTES

With the exception of mining wastes, the effects of Industrial Wastes on the components of the biological community are discussed collectively for the entire Basin. Wastes from individual factories are similar in constituents throughout a particular industry, the major differences between factories being primarily the strength or concentration of the waste components which vary mainly with dependence upon the size or capacity of the factory and the volume of diluting water in the receiving stream. For example, the ten beet-sugar mills in the South Platte Basin all discharge wastes containing large quantities of organic and suspended materials, and large numbers of bacteria.

Mining wastes are discussed on an individual basis for each subbasin in which investigations were carried out, because the deleterious waste components vary from area to area. For example, in some areas acids are significant while in another area heavy metals may be the principal pollutant. The difference between the subbasins are dependent upon the geological formations, the minerals mined, mining practices and current activities, and the principal source of contaminants within the mining complex.

Beet-Sugar Processing

During autumn and winter the beet-sugar industry discharges the largest quantity of putrefying organic material (1,800,000 population equivalents) to the Basin's streams (11). This value is nearly twice that of all the municipal wastes (910,000) discharged in the Basin. The points of wastewater discharge are as follows:

Brighton - South Platte River
Longmont - St. Vrain Creek
Loveland - Big Thompson River
Johnstown - Little Thompson River
Eaton - Eaton Draw to Cache la Poudre River
Greeley - Cache la Poudre River
Windsor* - Cache la Poudre River

Fort Morgan - South Platte River
Sterling - South Platte River
Ovid - South Platte River

*Mill closed in 1967.

As measured by the biochemical oxygen demand, the average beet-sugar mill discharge is greater than any other waste discharge, with exception of the City of Denver. As a result of the large quantity and the strength of the wastes discharged, the impacts on the receiving stream are great.

Algae

In unpolluted flowing waters, bottom-attached algae are the primary source of food upon which all aquatic animal life is dependent. In the presence of sunlight, chlorophyll in the algae converts carbon dioxide and water into carbohydrate food materials used by aquatic animals and, in this photosynthetic process, release dissolved oxygen. Oxygen, released through photosynthesis, is used in the respiration of aquatic animals and in the biochemical decomposition of dead putrefying organic matter. An abundant supply of oxygen for the rapid decomposition of rotting organic material aids in maintaining a clean stream.

As mentioned previously, the bottom attached algae (periphyton) is the principal plant form in the South Platte Basin streams. Artificial substrate sampling was used to sample the relative quantity of this algae. The growths on these substrates were measured by measuring the predominant photosynthetic phytopigment, chlorophyll a. Since the substrate growths were time related, these values are related to growth production rates. In addition, the quantity of chlorophyll, the photosynthetic catalyst, is indicative of the oxygen producing potential of the growths present at the time of sample retrieval.

The results of these analyses show that pollution of the waterways with beet-sugar wastes reducedthe quantity of attached algae. Figure 13 illustrates the change in the amount of attached algae in the South Platte River after the discharge of wastes from the Great Western Mill at Sterling, Colorado. At stations upstream from the discharge, as well as 50 miles downstream, the data show that there naturally was a higher algal crop during the period of sampling during beet-sugar waste discharge when compared to the sampling period prior to the waste discharge (i.e., September vs. October samples). The addition of beet-sugar wastes lowered the algal growth rate for at least 27 miles downstream from the effluent.

A substantial reduction in algal growth was observed downstream from the Great Western Longmont Mill discharge to St. Vrain Creek (Figure 1[illegible]). Upstream from this discharge, little natural

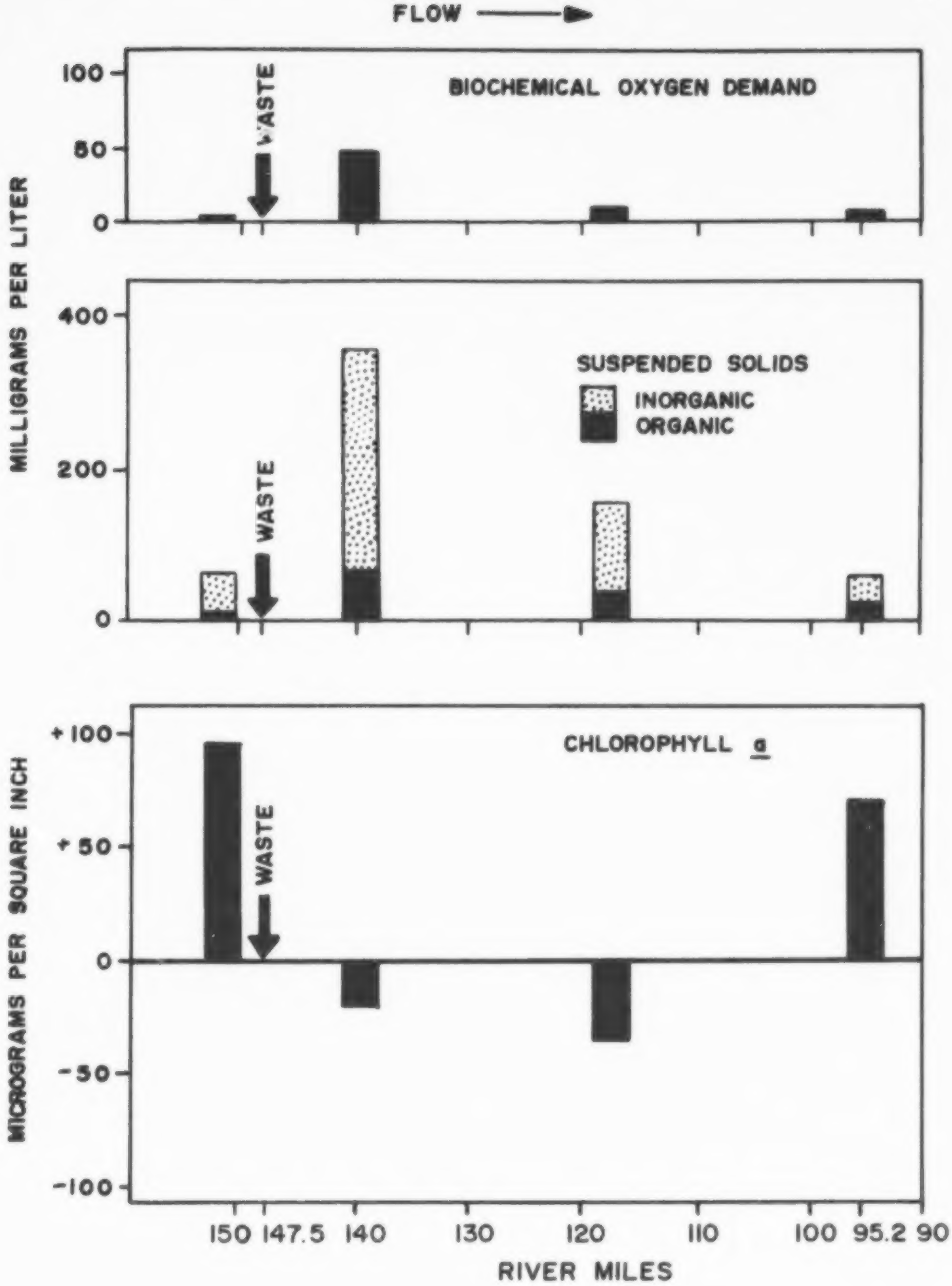


FIGURE 18. ALGAL CHANGES (CHLOROPHYLL a) AS AFFECTED BY BIOCHEMICAL OXYGEN DEMAND AND SUSPENDED SOLIDS, SOUTH PLATTE RIVER, STERLING TO OVID, COLORADO, 1963.

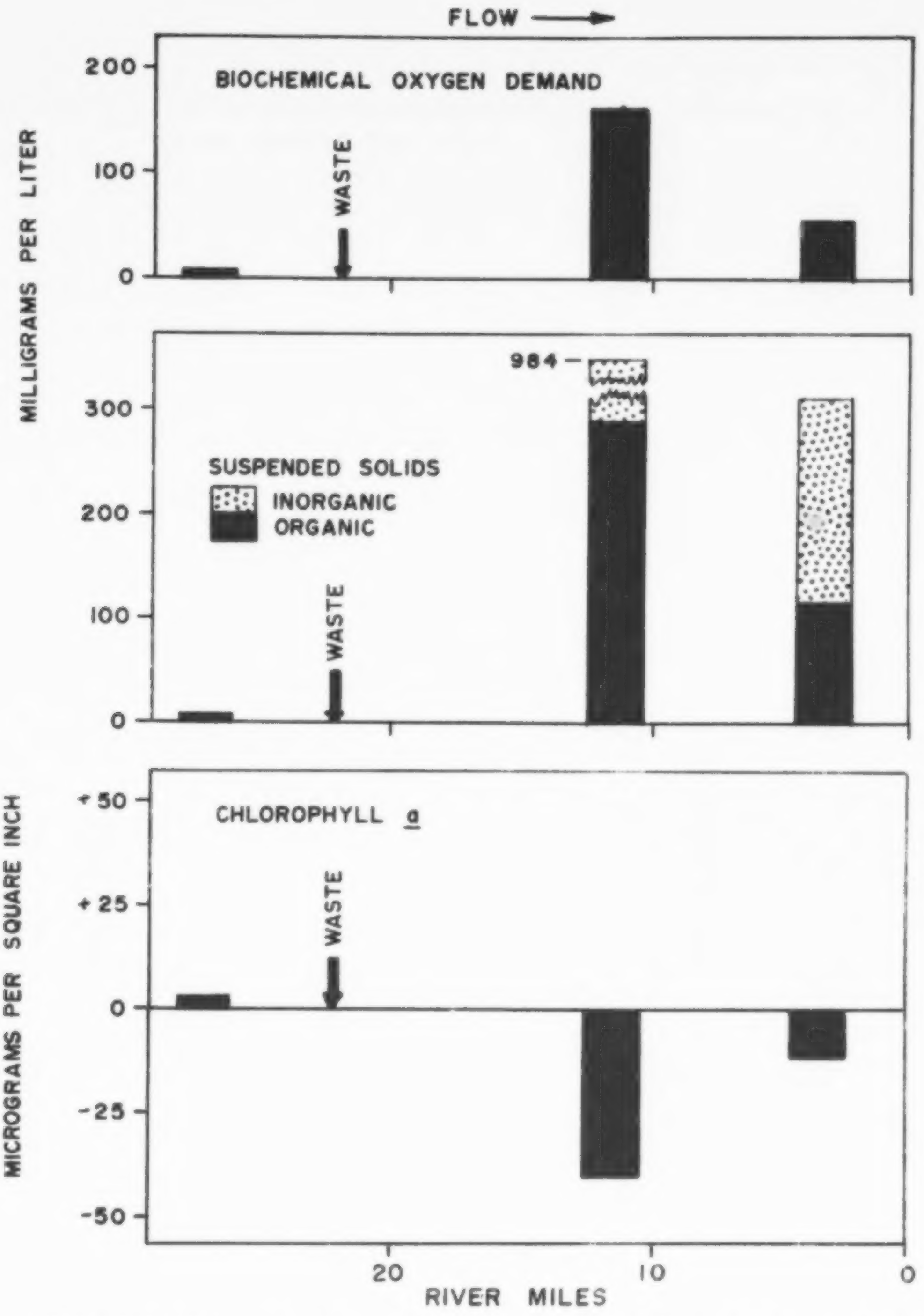


FIGURE 19. ALGAL CHANGES (CHLOROPHYLL a) AS AFFECTED BY BIOCHEMICAL OXYGEN DEMAND AND SUSPENDED SOLIDS, ST. VRAIN CREEK, 1964.

change in algal masses was observed between the periods of sampling.

The large quantities of suspended solids in improperly treated beet-sugar wastes shown in Figure 20 were one of the causes of reduced algal production. These solids reduced the penetration of light, thereby limiting the energy available for photosynthesis, and buried and smothered algal cells that were present before the waste discharge.

Large quantities of suspended solids discharged in wastes high in biochemical oxygen demand were exceptionally detrimental (Figures 18 and 19). The destruction of algae, by suspended solids, reduced the quantity of algal-produced oxygen available for biochemical decomposition. This extended the distance and time required for the stream to assimilate the pollution added to it.

Slime Growths

Slime growths were found below all beet-sugar waste discharges. Suspended slime growths floating downstream and slime covered rocks and logs are aesthetically revolting to both sight and touch. Slime growths appear to be directly related to biochemical oxygen demand and inversely related to suspended solids.

Field observations indicate that in streams receiving improperly treated beet-sugar wastes, where the BOD exceeds 10 mg/l, slime growths always are present; and as the concentration of suspended

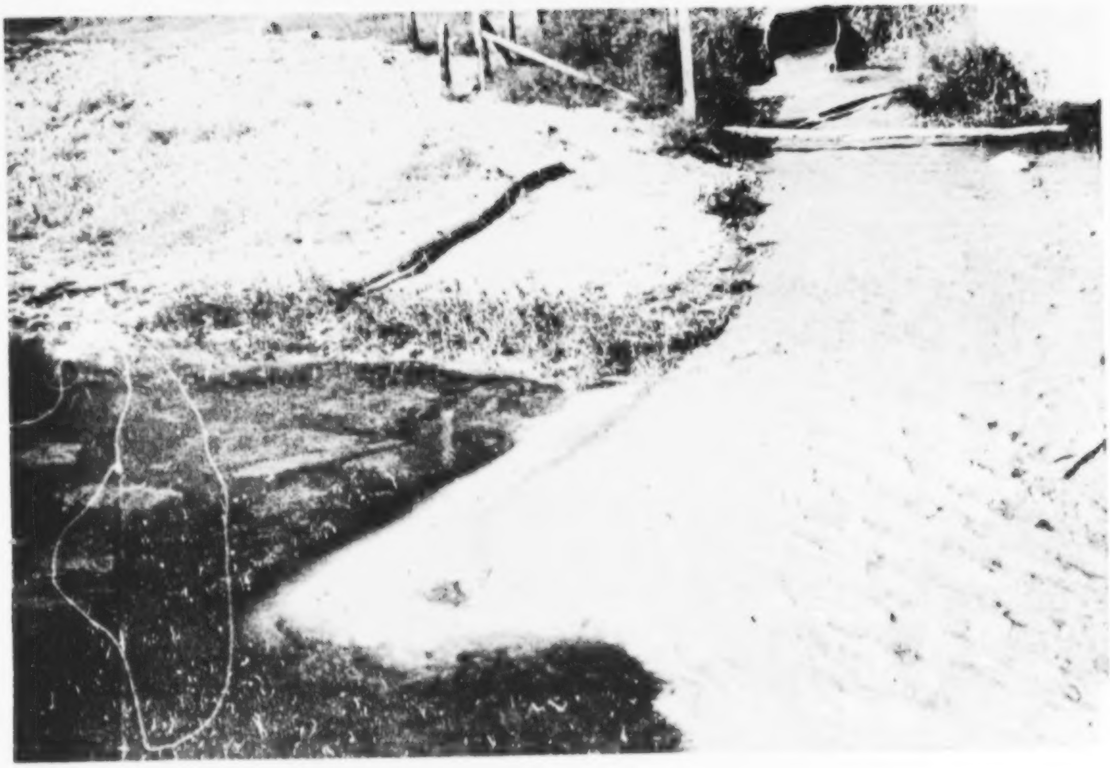


FIGURE 20
PHOTOGRAPH OF WASTE EFFLUENT FROM THE LONGMONT BEET-SUGAR MILL
ILLUSTRATING LARGE QUANTITIES OF SUSPENDED SOLIDS DISCHARGED
OCTOBER [illegible]

solids increases the predominant slime growths change from filamentous slime bacteria (Sphaerotilus) to the stalked protozoan (Vorticellidae) form; and a general inhibition of slime growths occurs when the solids concentration approaches and exceeds 100 mg/l. The reasons for these changes are as follows:

1. A portion of the BOD is sugar, lost in the manufacturing process, which is a basic nutrient for the filamentous slime bacteria (31).
2. As the concentration of suspended materials increases, large quantities become entrapped in the filamentous growths thus tending to smother or bury them.
3. Increased quantities of microscopic organic particles and bacteria accompany an increase in the total suspended solids, and because these serve as food for the solids-feeding protozoans, their population increases.
4. Even though the shorter flocculent protozoan growths are more tolerant of suspended solids than the "mop-like" bacterial growths, high concentrations of suspended solids will also eventually smother them.

The Johnstown, Colorado, Great Western Complex producing monosodium glutamate from Steffan's house waste discharged a waste that nurtured intense slime growths in the Little Thompson River. Slime growths were found here throughout the year because of continuous waste discharge. Carried downstream, slimes entered the Big Thompson River where death and subsequent decomposition resulted in dense black organic sludges that covered the river's bottom.

During the beet-sugar processing season, wastes discharged into the Big Thompson River from Great Western's Loveland Factory stimulated the growth of slimes that covered the river bottom as a thick blanket. Beneath the white slime growths, dense black organic sludges developed. These sludges were the result of decomposing older slime growths which had been buried by new growths.

Slimes inhibited algal growths through dense colonization of available attachment sites, thus excluding algae, and by dense overgrowth that smothered established algal colonies. The slime-infested reach of the Little Thompson River supported only six percent of the algal growth present upstream from Great Western's Johnstown waste discharge. Following the addition of beet-sugar wastes from Great Western's Loveland Mill, slimes drastically reduced algal growths in the Big Thompson River (Figure 21).

Data for periphytic growths collected in the Cache la Poudre River illustrate the change from an algal to a slime growth community

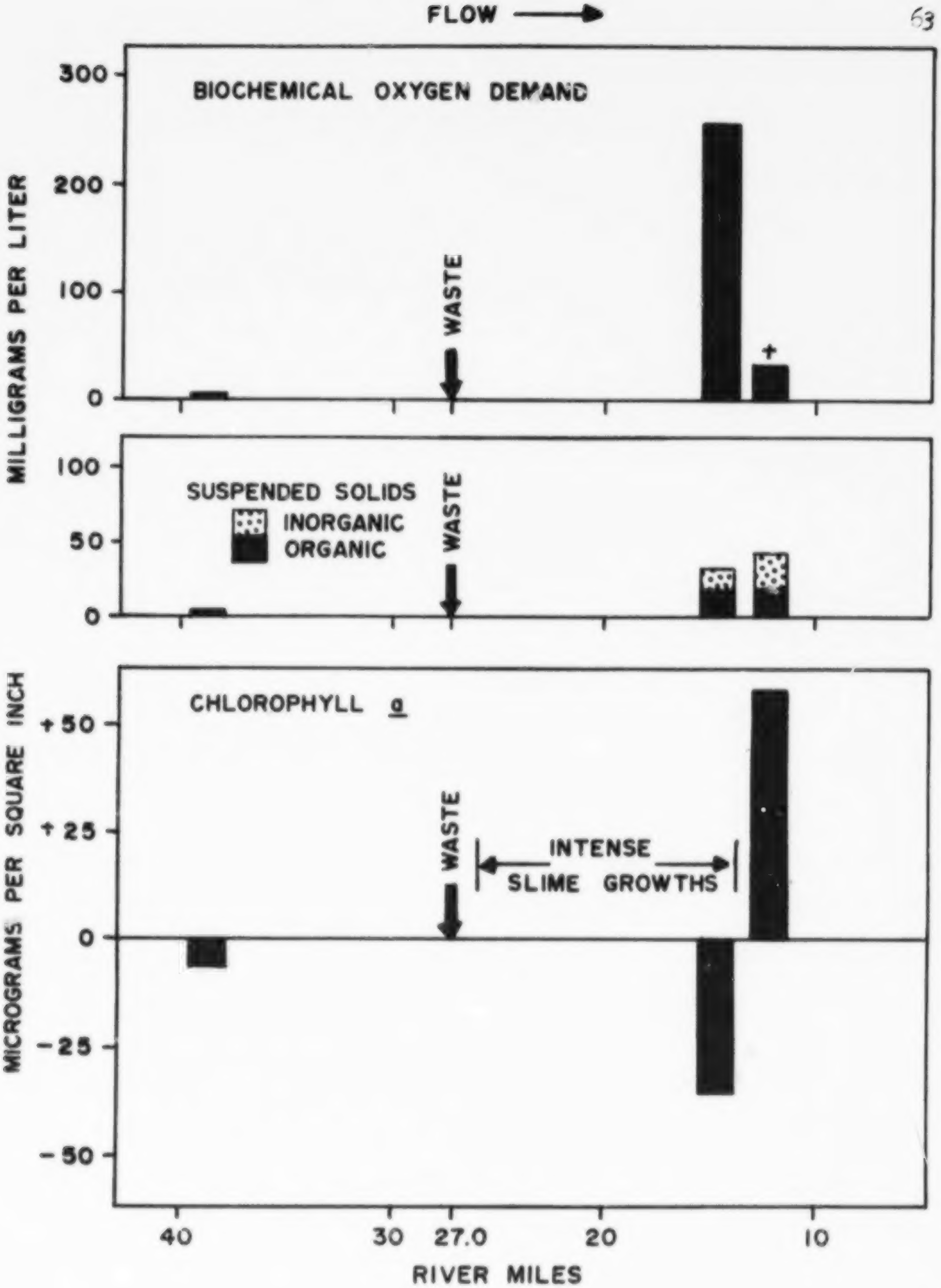
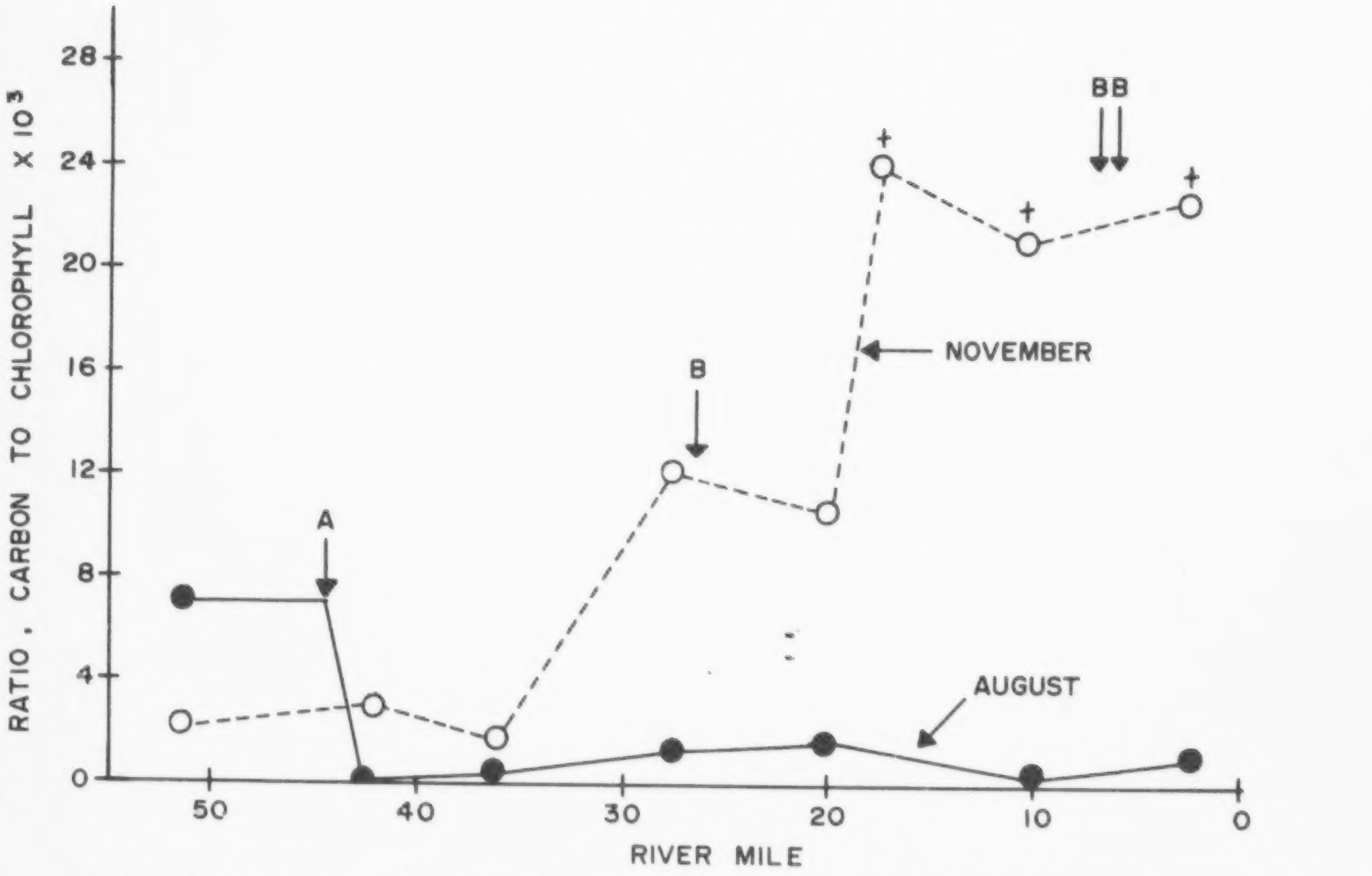


FIGURE 21. ALGAL CHANGES (CHLOROPHYLL a) AS AFFECTED BY BIOCHEMICAL OXYGEN DEMAND AND SUSPENDED SOLIDS, BIG THOMPSON RIVER, 1964.

(Figure 22). The carbon-chlorophyll ratio is indicative of this change because both algal and slime growths are carbonaceous. However, since algae contain chlorophylls and the slimes do not, a community with a high carbon content and a low chlorophyll content would be predominantly slime growths. In August the carbon-chlorophyll ratios were extremely low, especially in the fertile reach downstream from Fort Collins, an indication of the predominance of viable active algae.

In November, in the reach of stream affected by the beet-sugar wastes large quantities of carbon in relation to the quantities of chlorophyll were found, which is indicative of the preponderance of slime growths. The true ratios may be higher than those shown because the chlorophyll quantities were so low it was not detectable. Also, the carbon values were lower than in many other slime infested areas. This probably is a result of slime growth reduction by sedimentation of the suspended solids that fluctuated between 10 and 89 mg/1.

In addition to inhibiting algae, slimes destroy animal life. Figure 23 shows slime growths on a crayfish collected from the South Platte River a short distance downstream from the point where it is joined by the beet-sugar waste polluted Cache la Poudre River. These slime growths were in the process of over-growing the crayfish's gills, leading to suffocation.



A. FORT COLLINS SEWAGE ; B. BEET-SUGAR WASTES ; + GREATER THAN VALUE SHOWN (LOW VALUES ARE INDICATIVE OF ALGAE, HIGH VALUES ARE INDICATIVE OF SLIMES)

FIGURE 22. RELATIVE DENSITY OF ATTACHED SLIME AND ALGAL GROWTHS, CACHE la POUDRE RIVER, COLORADO, 1966.

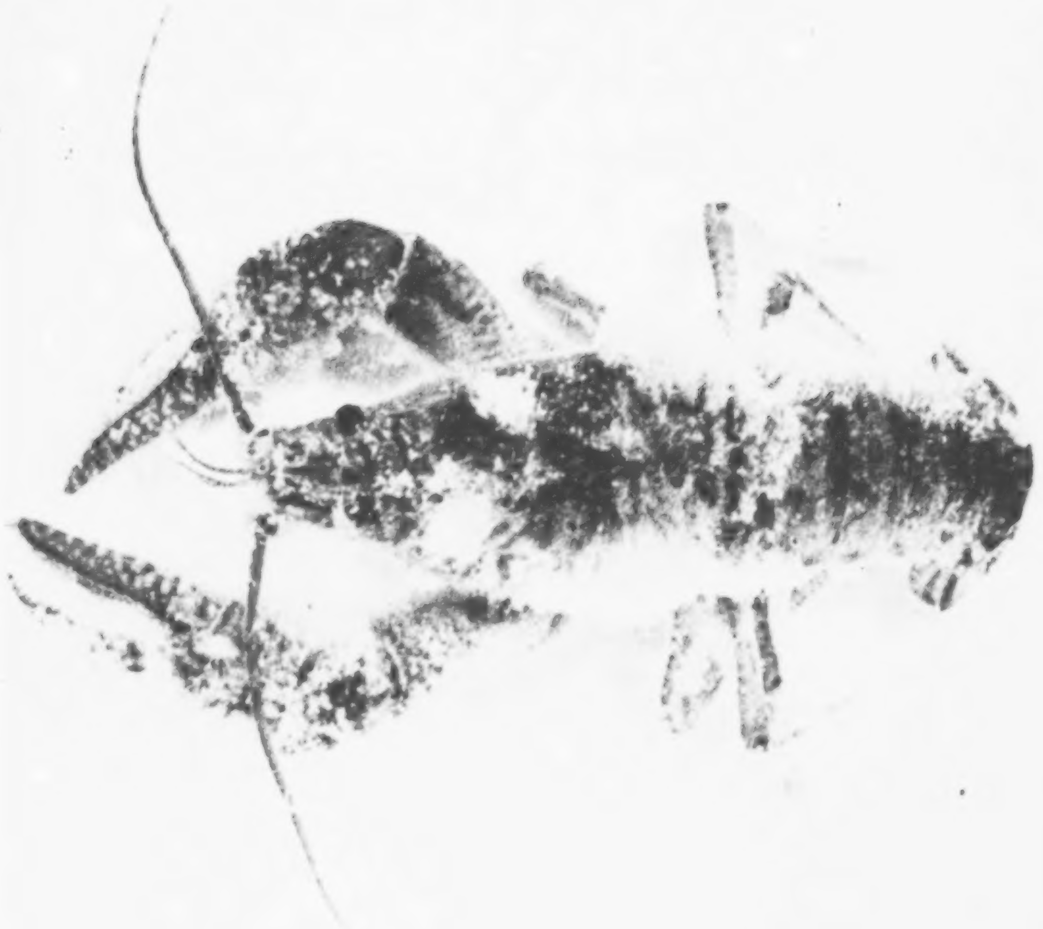


FIGURE 23

PHOTOGRAPH OF CRAYFISH OVERGROWN WITH SLIMES.
SOUTH PLATTE RIVER, KERSEY, COLORADO
OCTOBER 1964.

Bottom Animals

Stream beds in unpolluted water are inhabited by many kinds of bottom animals sensitive to pollutants, including mayflies, caddisflies, and stoneflies.* Each variety is limited in number by food supply, competition, and predation. Some types of pollutants adversely affect the stream's chemical and physical conditions by increasing the dissolved and suspended materials, creating sludge deposits, and altering the natural stream temperatures. Adverse chemical and physical conditions eliminate those organisms that require clean water. The organism varieties are eliminated in the order of sensitivity and as the strength of the pollutant increases. Elimination of all bottom animals indicates that the pollutant is toxic to the entire community, either directly or through the adverse chemical conditions associated with the decomposition of the pollutant. When the surviving animals increase substantially in numbers, the pollutant is supplementing their usual food supply. Considering these principles, the community of bottom animals indicates the degree, extent, and type of pollutant.

Bottom animals are a vital link in the aquatic food chain: plant tissue to bottom animal to fish. Some bottom-inhabiting immature insects such as black flies, biting midges, nonbiting midges, and mosquitoes may, upon emerging as terrestrial adults, transmit diseases and create nuisance. Tolerant sludgeworms and bloodworms flourish in sludge deposits where they digest organic materials, thereby accelerating the stream's assimilation of the pollutant.

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* All insects are in the aquatic stages of their life cycles (nymphs or larvae).

The community of bottom animals indicated that beet-sugar wastes were a serious pollutant. The response of bottom organisms to pollution in the South Platte River from the Sterling mill, and in St. Vrain Creek from the Longmont mill are illustrated in Figures 24 and 25. The elimination of tolerant sludgeworms as well as more sensitive forms testifies to the intensity of the pollution. Excessive quantities of organic solids discharged from these mills were the cause. In St. Vrain Creek, a net with a one-square-foot opening exposed to the current for one minute retained a quart of the larger chunks of sugar beets (Figure 26). Additional beet parts were found covering the rivers' bottoms and rolling downstream as part of the bed-load. The byproducts of putrefaction of beet-sugar wastes were the cause of reducing even the tolerant worms. By this action, pollution was severe enough to inhibit the digestion of organic materials in the streams; worms consume several times their weight in organic materials each day, thereby reducing the BOD of the sludge. Eventually self-purification of the polluted streams by the settling of solids to form sludge beds, and bacterial decomposition, changed the

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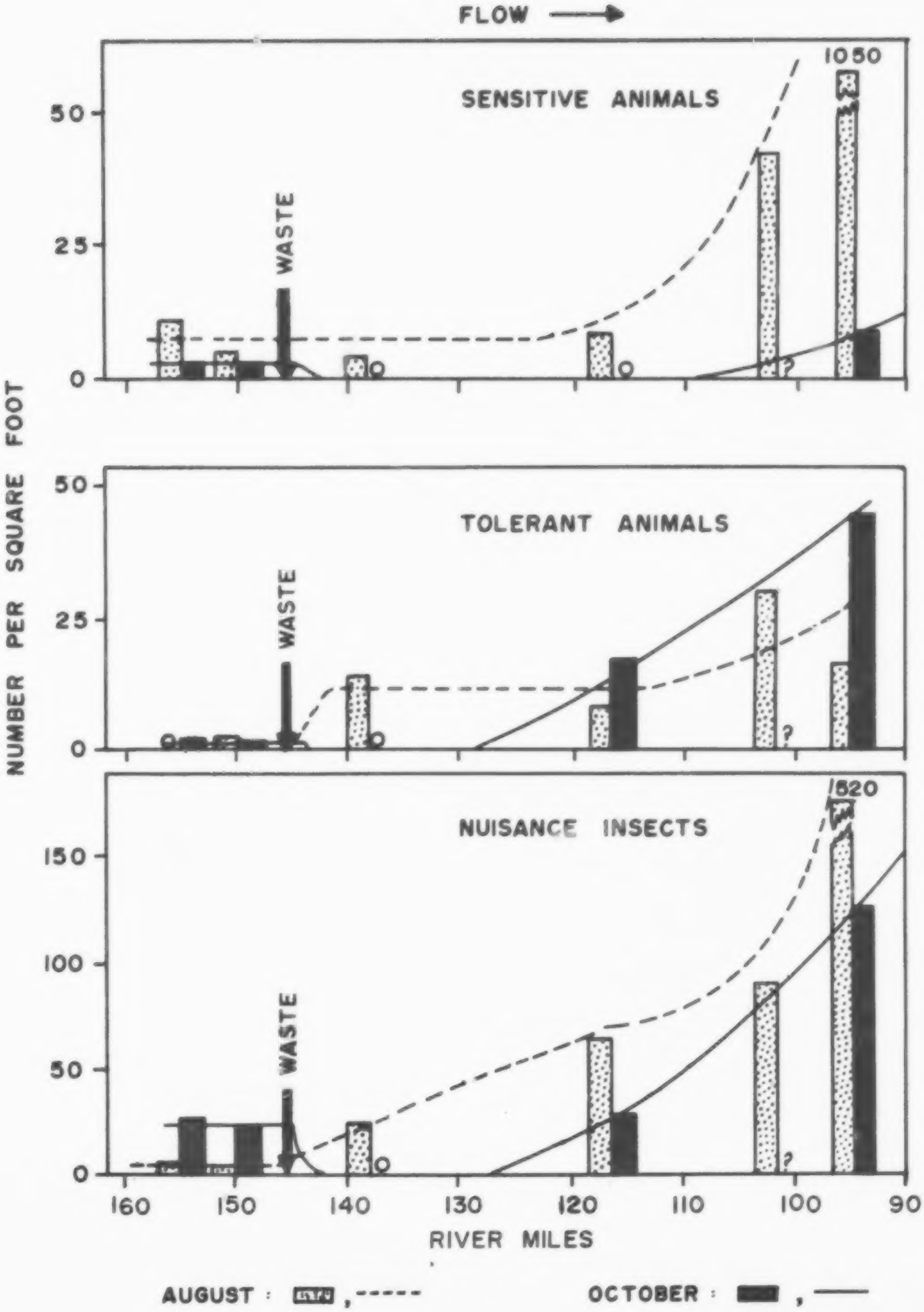

FIGURE 24. BOTTOM ANIMALS, SOUTH PLATTE RIVER, STERLING TO OVID, COLORADO, 1963.

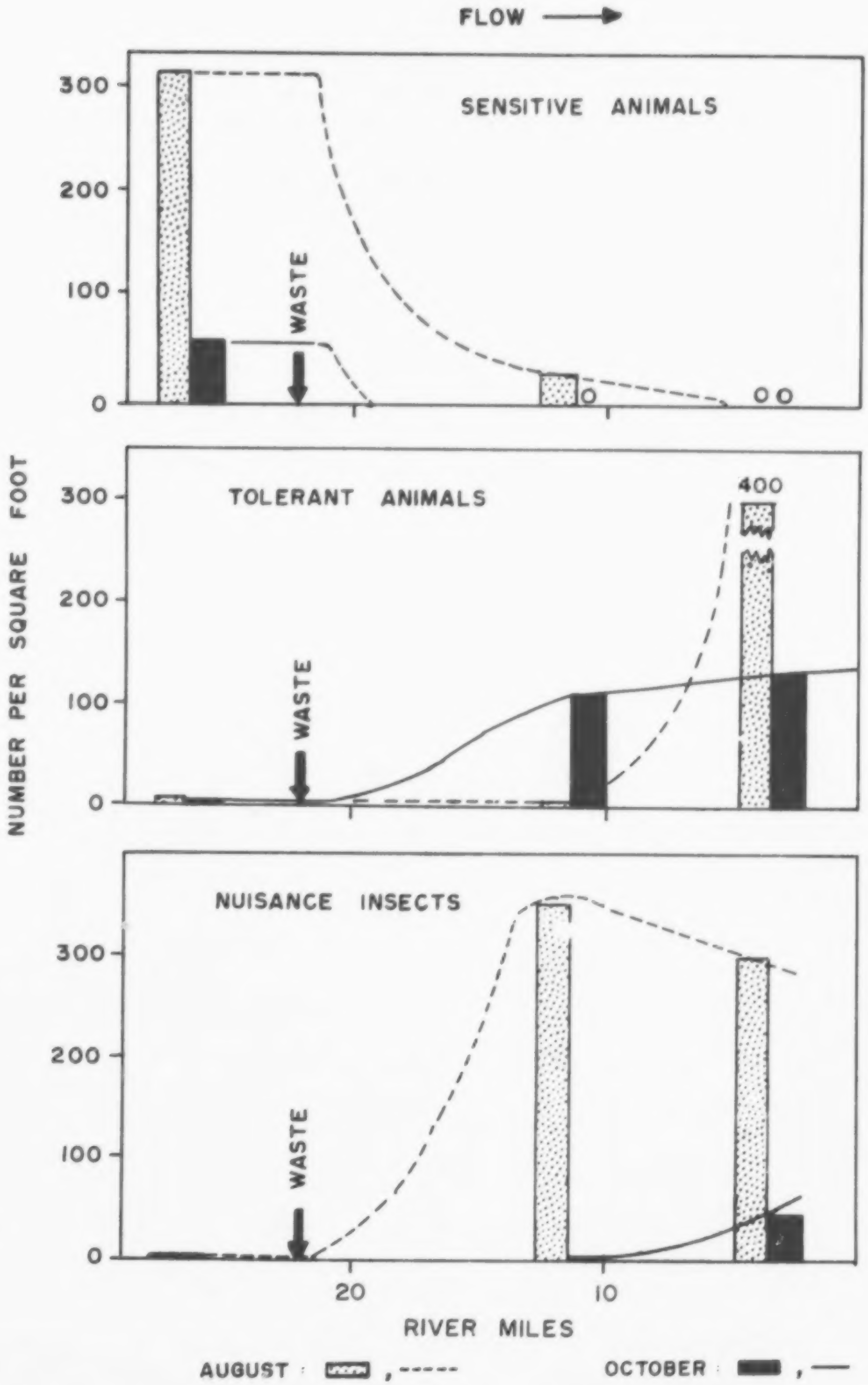

FIGURE 25. BOTTOM ANIMALS, ST. VRAIN CREEK, COLORADO, 1964.

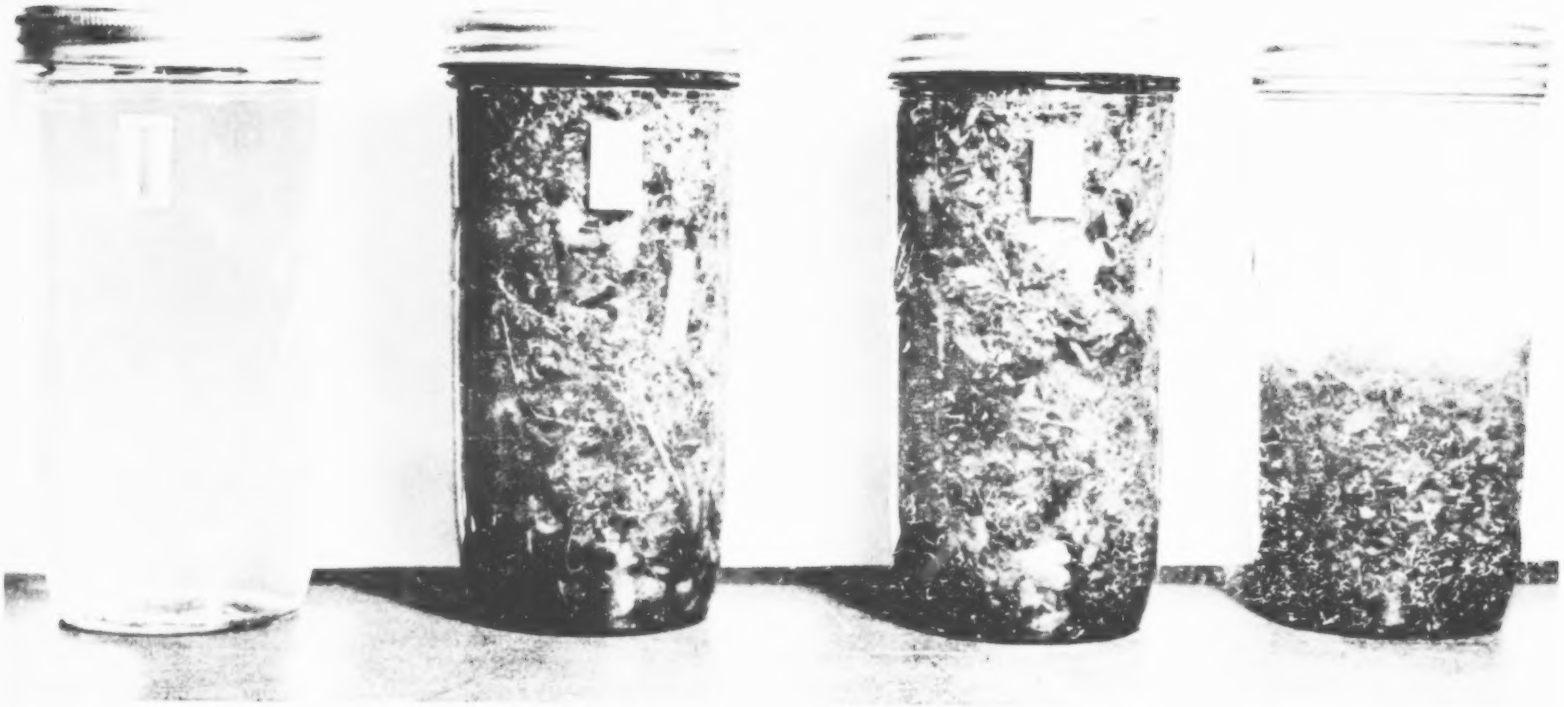

FIGURE 26

SUSPENDED CHUNKS OF SUGAR BEETS, ST. VRAIN CREEK, OCTOBER 1964: (1) ABOVE LONGMONT, COLORADO; (2) U.S. HIGHWAY 87 BELOW LONGMONT; (3) 1 MILE ABOVE CONFLUENCE WITH SOUTH PLATTE RIVER; (4) SOUTH PLATTE RIVER, HIGHWAY 60 (MATERIAL RETAINED IN A NET WITH A SQUARE-FOOT OPENING EXPOSED TO THE CURRENT FOR ONE MINUTE).

water quality to a level that permitted the downstream bottom animals to survive in gradually increasing numbers. Organisms feeding on the remaining beet solids soon increased in numbers to levels much higher than those observed in the river upstream from the beet waste discharges.

In late summer, several months after termination of the seasonal waste discharge by the mills, bottom animals significantly increased in numbers downstream from the mills (Figures 24 & 25). Since downstream algal growths decreased (23%) in the reach from Sterling to Ovid, Colorado, algae did not provide the necessary food for the increase in number of organisms. Therefore, a food supplement remained in the stream. This was in the form of sludge deposits that were observed downstream from all mills. Sludges were gradually being resuspended as the stream eroded into sludge banks. With a steady rate of erosion, the concentration of suspended solids will increase with farther downstream travel of a water mass. With the erosion of sludge deposits, the quantity of suspended organic food material increases. With fluctuating erosion rates, the probability of upstream erosion having occurred increases farther downstream. Thus, the reliability of sludge originating food also increases in water reaches farther downstream. The community of bottom animals attached to substrates raised from the river bottom responded with a similar increase in numbers downstream (Figure 27). Their food source was grown

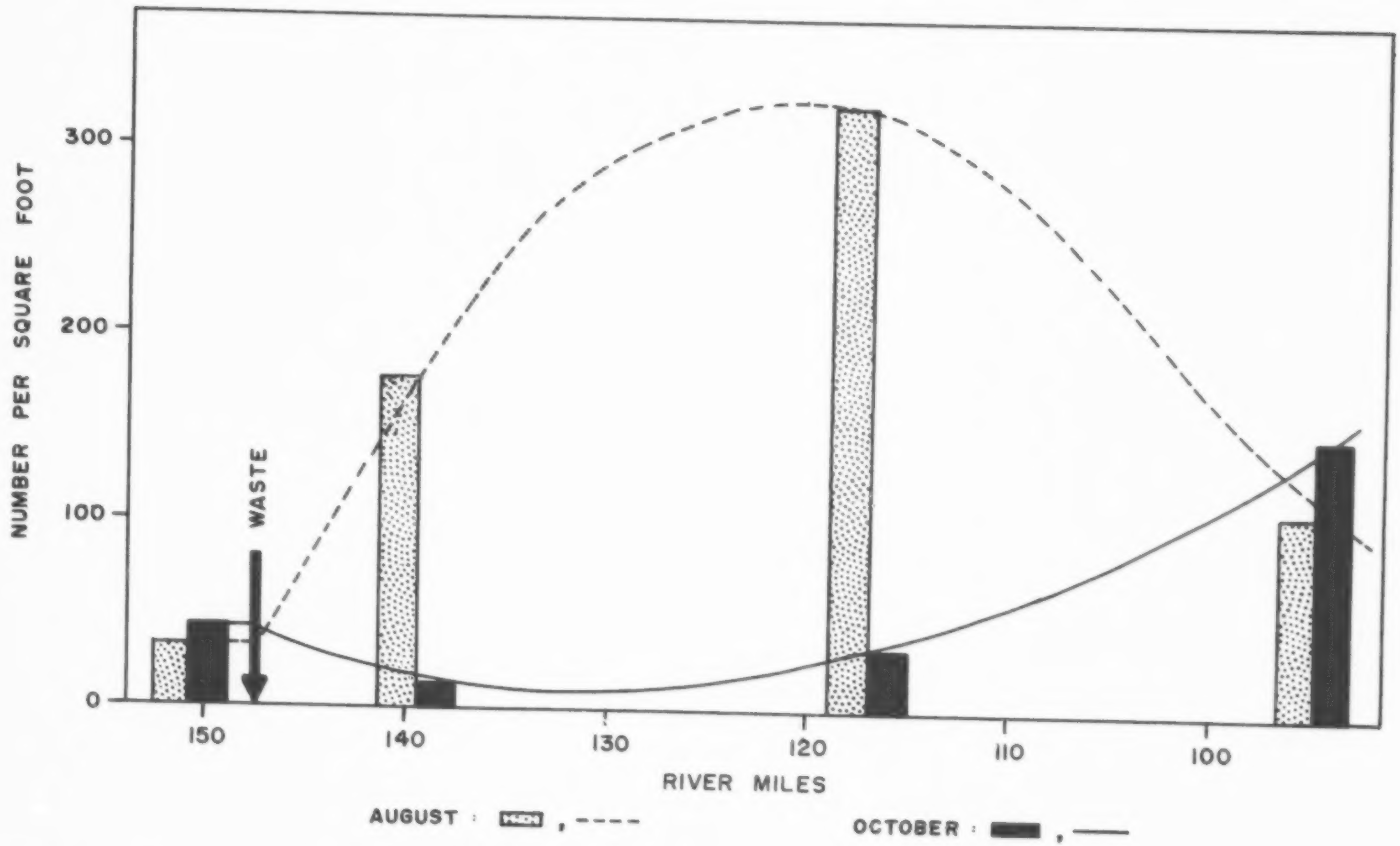

FIGURE 27. BOTTOM ANIMALS ON ARTIFICIAL SUBSTRATES, SOUTH PLATTE RIVER, STERLING TO OVID, COLORADO, 1963.

on the substrate as algae (no increase) supplemented with food drifting downstream. There was residual pollution affecting the stream biota several months after the last discharge of waste.

The artificial substrates, installed to remove the effects of variable bottom conditions, produced animal responses similar to those found with direct bottom sampling (Figures 27 & 28). These results show that pollutional effects were also present in the flowing water and were not confined to putrefying bottom sludges.

The Little Thompson River was also severely polluted. Wastes from the Great Western Complex at Johnstown, Colorado, limited the bottom animal population to an occasional sludgeworm.

The wastes discharged from the beet-sugar mill at Loveland, Colorado, were relatively low (40 mg/l) in suspended solids in the Big Thompson River, but nutrients supported dense slime growths. Dead slimes formed sludges resulting in a bottom animal community indicative of pollution (Figures 29 & 30). Downstream the river was rapidly recovering from the effects of pollution. It was again polluted downstream from the confluence of the Little Thompson, a polluted tributary. Two miles upstream from the confluence with the South Platte River, extensive sludge deposits in the Big Thompson River nurtured large numbers of sludgeworms.

Increases of bottom animal numbers downstream from the sugar beet mills was detrimental to health and welfare because of the

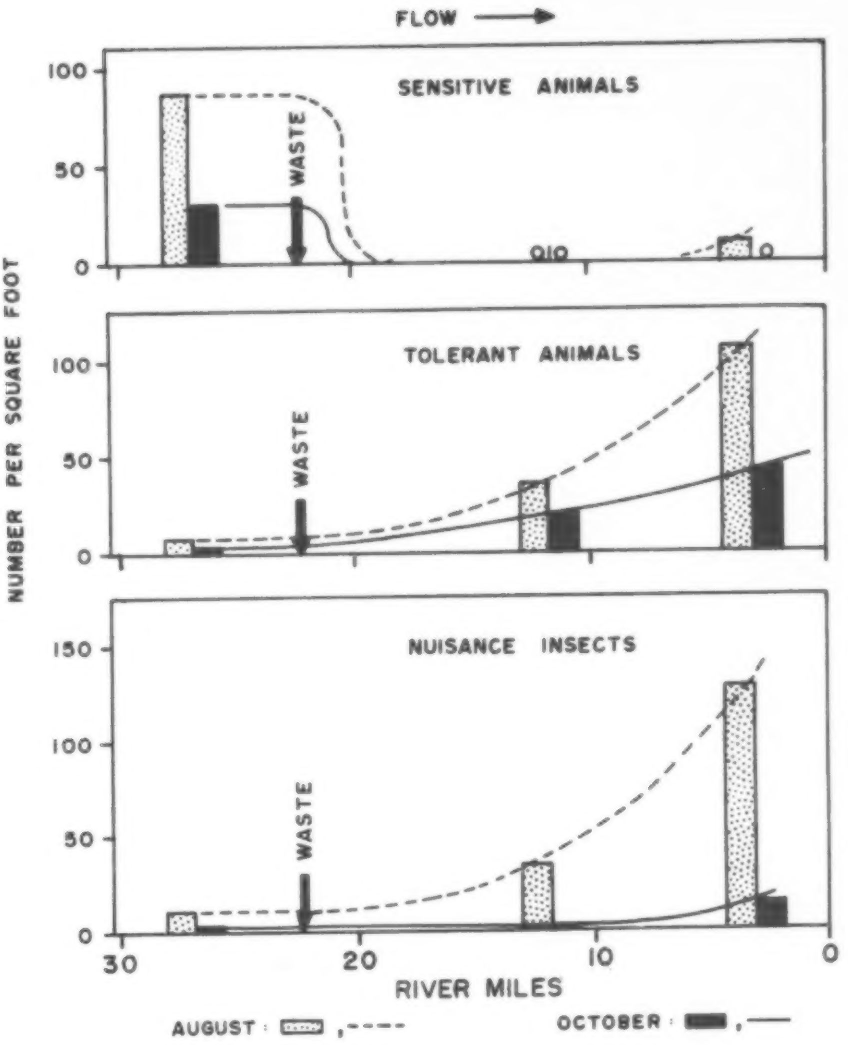

FIGURE 28. BOTTOM ANIMALS ON ARTIFICIAL SUBSTRATES, ST. VRAIN CREEK, COLORADO, 1964.

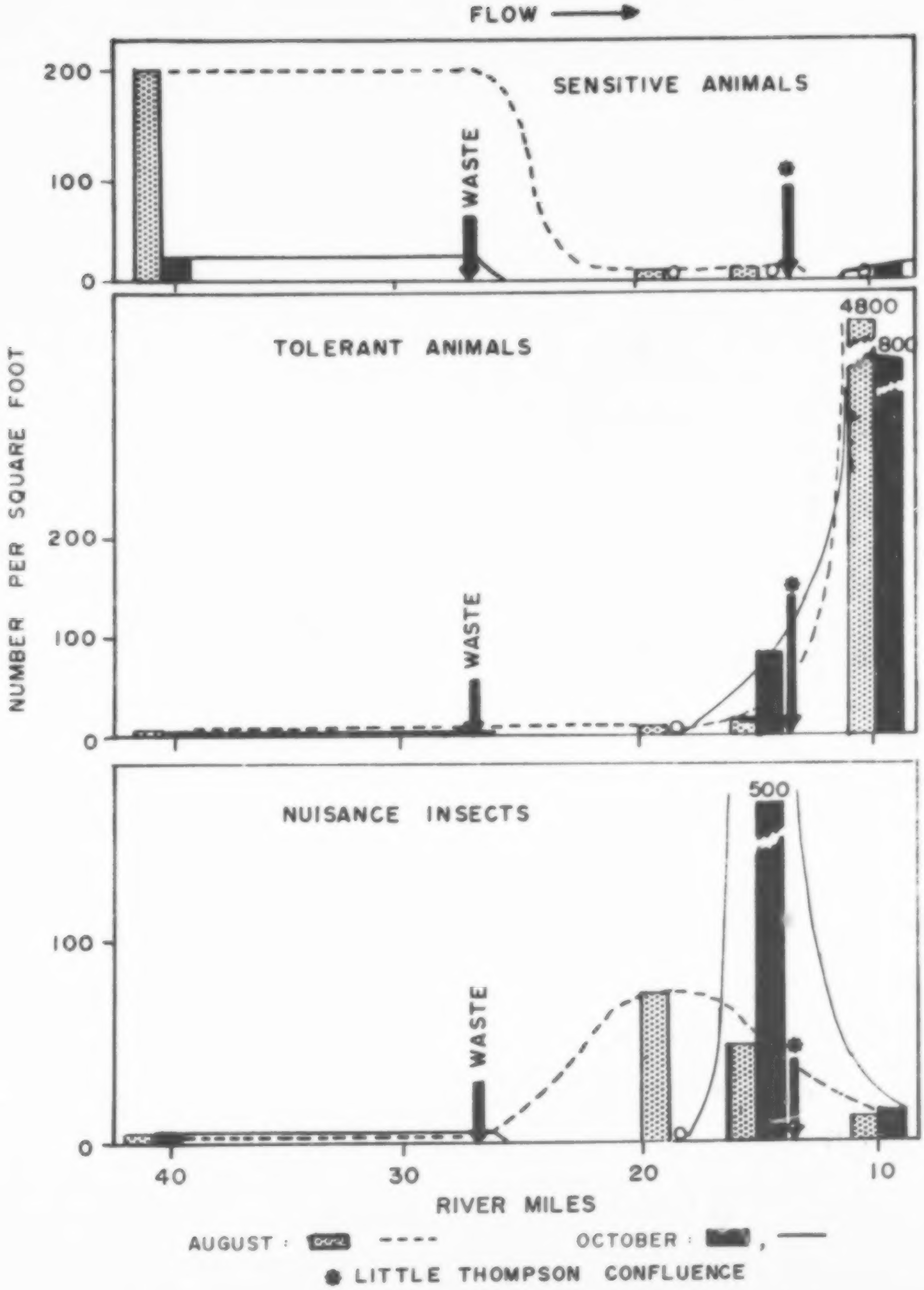

FIGURE 29. BOTTOM ANIMALS, BIG THOMPSON RIVER, COLORADO, 1964.

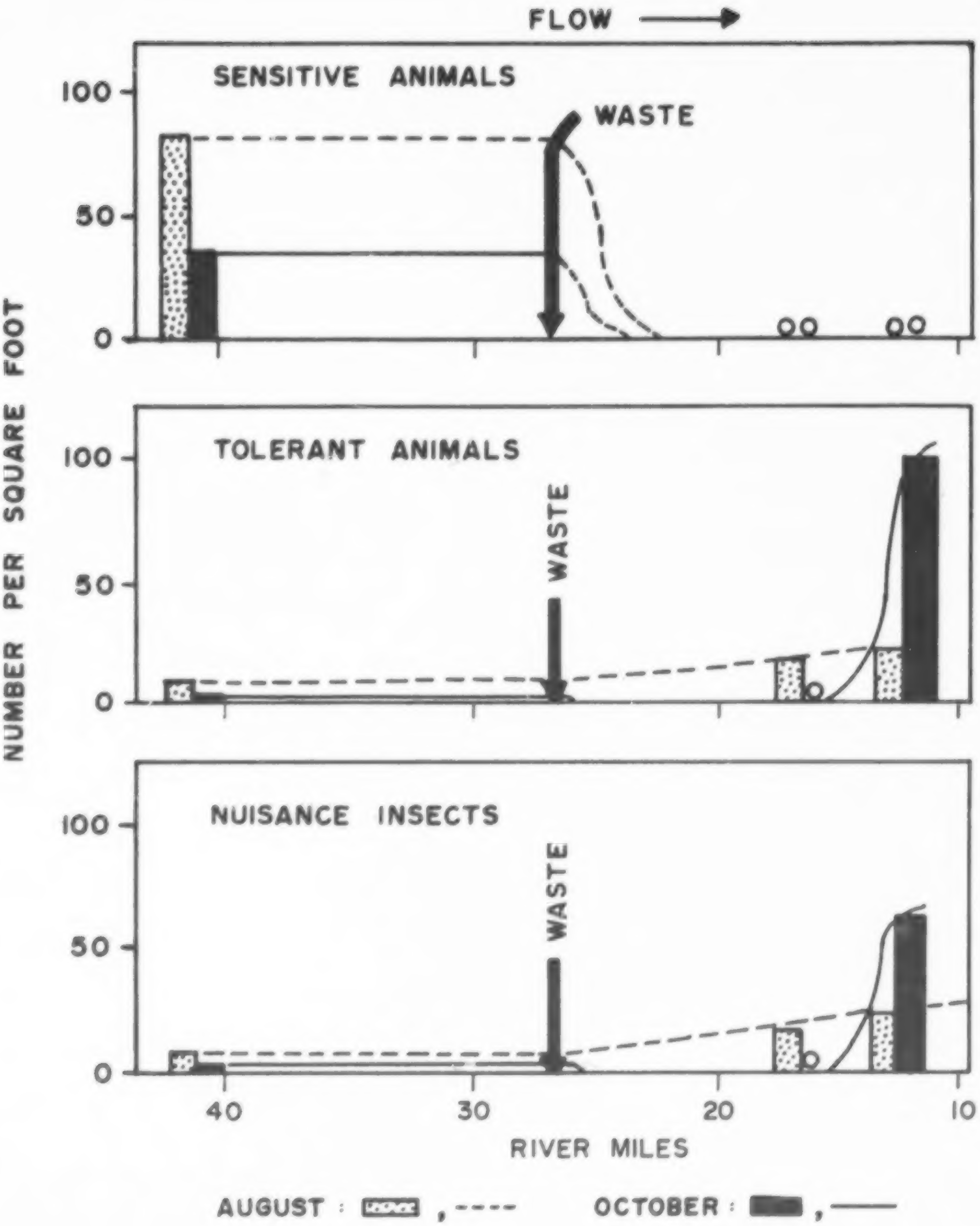

FIGURE 30. BOTTOM ANIMALS ON ARTIFICIAL SUBSTRATES, BIG THOMPSON RIVER, COLORADO, 1964.

increase in noxious insects that are known to transmit diseases and create nuisances (Figures 24, 25, 27, 28, 29 & 30). Black flies (or buffalo gnats), biting midges, nonbiting midges, and mosquitoes increased in numbers as a result of the increased food supply. The South Platte River's braided pattern of several intertwining channels is a factor in the production of noxious insects. The main river flow follows one of the channels. Changes in channels result because of the aggradation of sand-bars, blockage with ice, or during floods. Thus, many stagnant pools are produced which are scattered throughout the river bottoms in the abandoned channels. The beet-sugar wastes trapped in these pools accelerate and intensify stagnation of these pools, thus contributing to the production of an excellent mosquito "brooder." Organic solids deposited in irrigation canals also feed mosquitoes breeding in residual puddles after diversion ceases.

Organic solids from beet-sugar mills fed flies for many miles (Figure 24). Some of the flies at Ovid, Colorado, may be attributed to increased food which originates 50 miles upstream (waste from the Sterling mill). The adult biting flies are serious pests. Mosquitoes serve as vectors for many diseases of man, livestock, and wildlife. Mosquito-borne encephalitis, often fatal to man, occurs with abnormally high frequency in the South Platte Basin. Black flies (or buffalo gnats) also transmit diseases to man, livestock and wildlife. Their exceptionally painful bloodsucking bites reduce the vitality of exposed livestock - hordes of black flies can literally kill mules with their attacks. At one station on the South Platte River, over 16,000 black fly larvae per square foot of substrate were found feeding on microscopic particles of sugar beets.

Figure 31 summarizes the pollutional impact on the mainstream of the South Platte River in the reach from the confluence of St. Vrain Creek downstream to the Colorado-Nebraska State-line. Compared to summer, in autumn four genera more of aquatic invertebrates were usually collected at the clean water sampling stations. This increase in number of genera is the product of two factors: 1) The summer samples do not contain some genera because they were in the adult terrestrial phase of their life cycles; later, in autumn the descendants of these adults appeared in samples as immature larvae or nymphs inhabiting the river. 2) During summer, some forms of recently hatched larvae may not have sustained sufficient growth to permit retention on the size-selecting sample-processing sieves; but, in autumn these forms had sustained sufficient growth for collection with the sampling procedure used. Figure 31 was adjusted for this discrepancy by subtracting the summer values from the autumn values - resulting in positive numbers for the natural increase in number of genera and negative values where pollution had reduced the values by elimination of the forms that could not tolerate the adverse conditions resulting from pollutants in the waterway. Using the changes

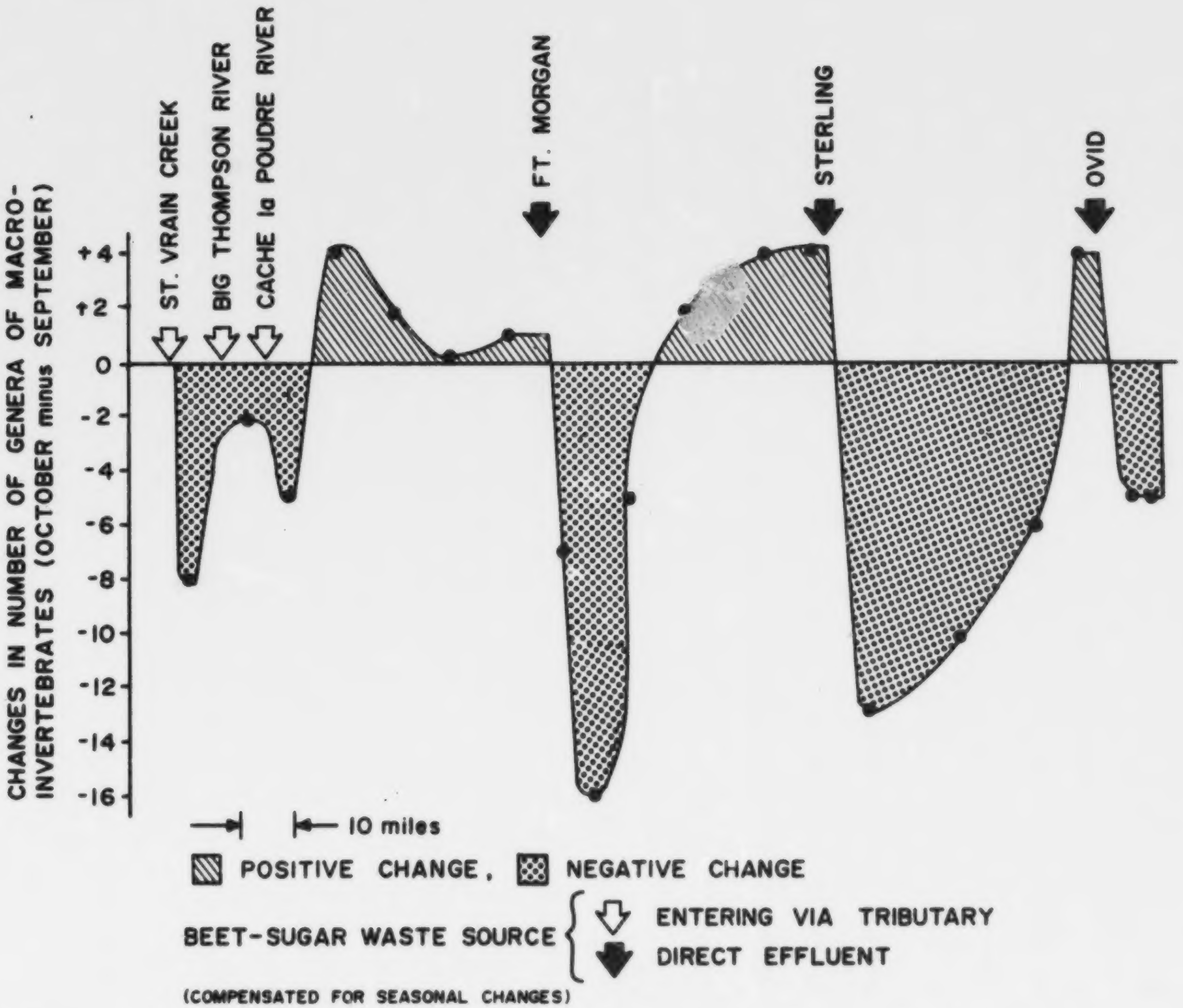

FIGURE 31. SUMMARY OF BEET-SUGAR WASTE EFFECTS ON BOTTOM ANIMALS IN THE SOUTH PLATTE RIVER, COLORADO.

in the bottom animal community as an indication of the extent of pollution, 53 percent, or 99 miles, of the stream illustrated in Figure 31 was polluted by beet-sugar wastes. To this 99 miles on the mainstream, the following tributary reaches may be added:

St. Vrain Creek--------------- 22 miles
Little Thompson River--------- 1 mile
Big Thompson River------------ 27 miles
Cache la Poudre River--------- 26 miles

resulting, in a total of 175 miles of polluted waterway due to the discharge of inadequately treated waste waters from nine beet-sugar mills.

Fish

In the past, the waters studied have supported trout downstream to near the Colorado-Nebraska State-line (10). With changes induced by man the trout were eliminated and warm water fishes today occupy the non-mountain streams of the Basin. Fish were present at most sampling points. However, the majority were tolerant carp, suckers, and many top minnows. At a few isolated stations game fish such as bass and sunfishes were also observed.

To ascertain the effects of beet-sugar wastes on fish life, sampling was conducted during August and November 1966 in the Cache la Poudre River. The results summarized in Figures 32 and 33 show a drastic reduction in the fish fauna in reaches subjected to beet-sugar

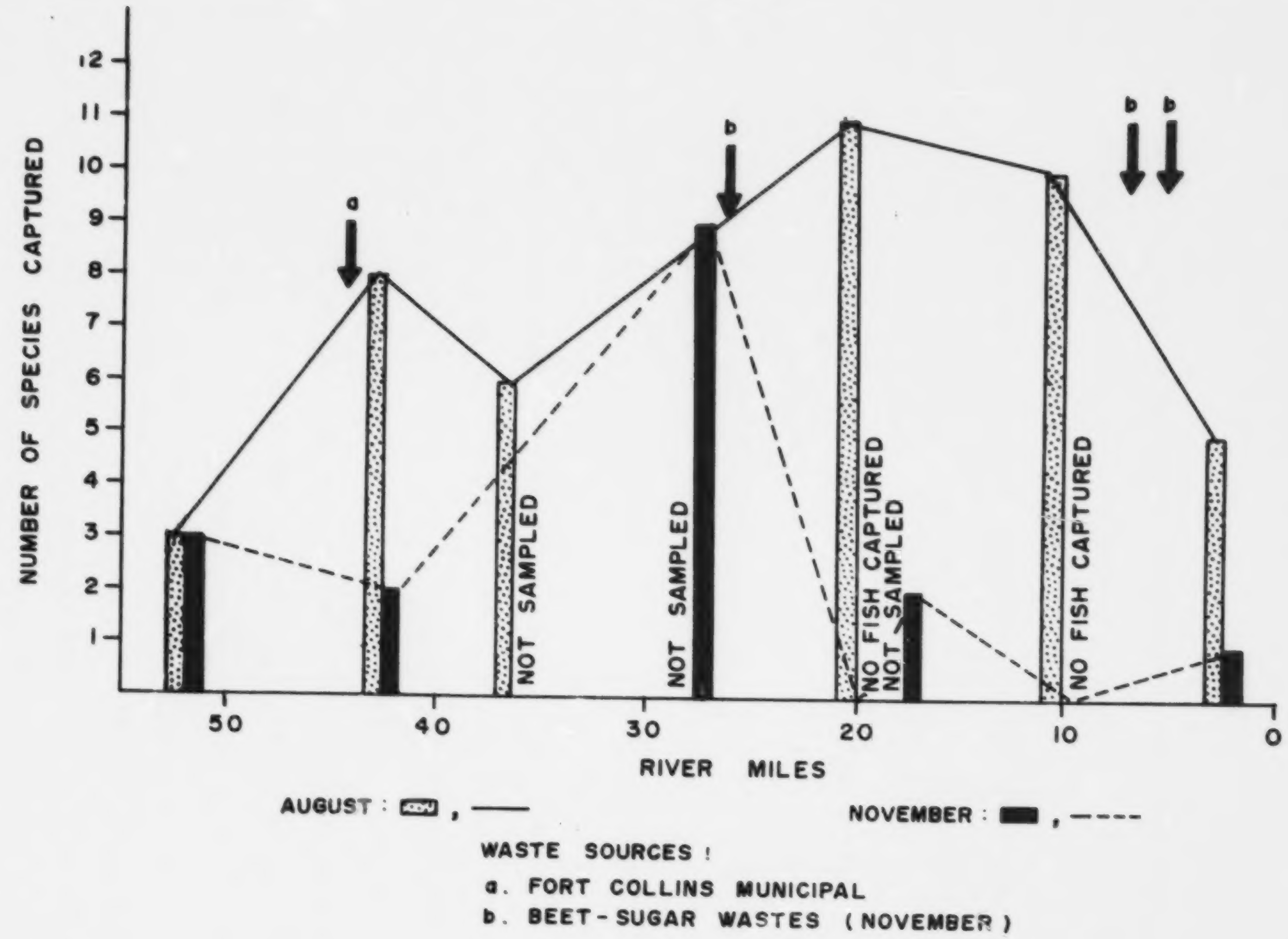

FIGURE 32. EFFECTS OF BEET-SUGAR WASTES ON THE VARIETY OF FISH, CACHE la POUDRE RIVER, COLORADO, 1966.

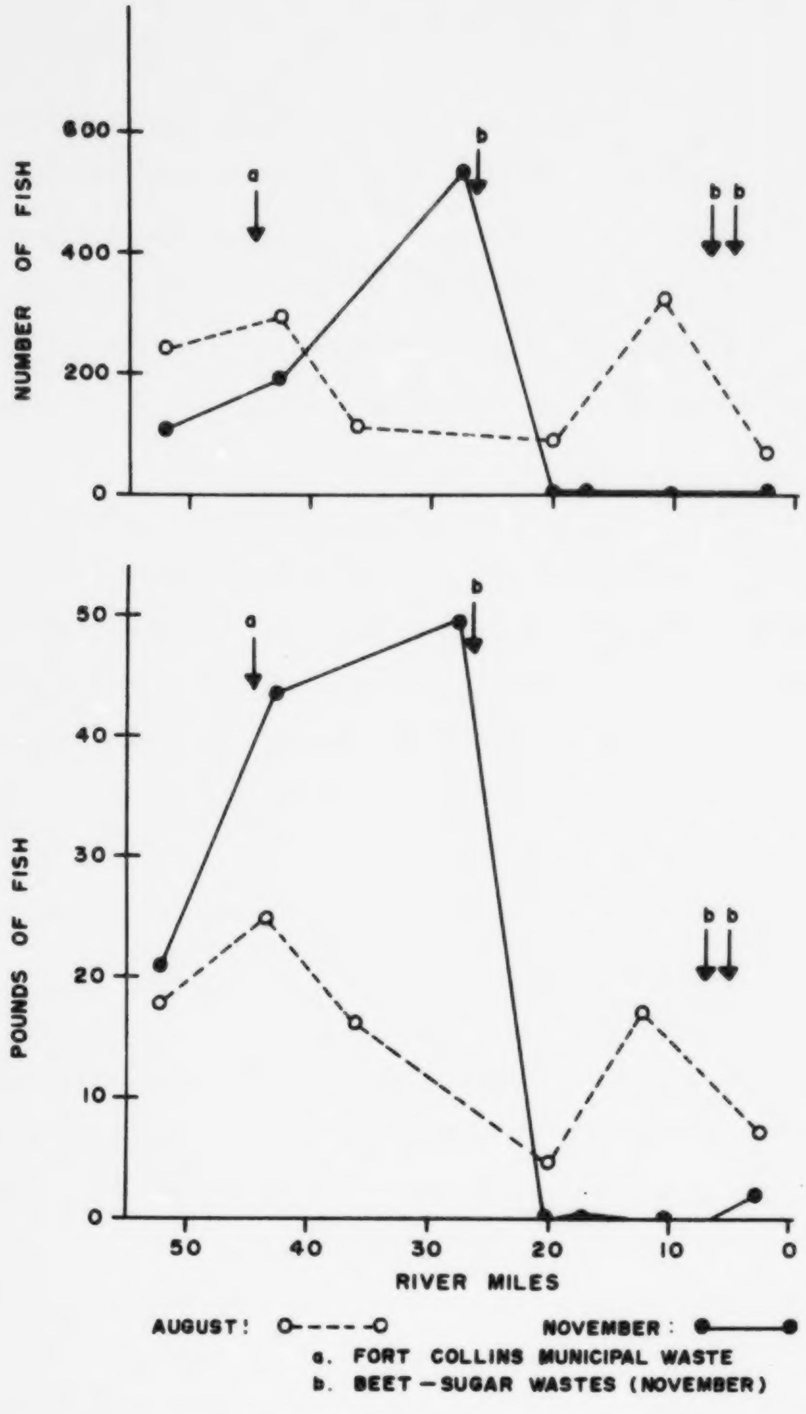

FIGURE 33. EFFECTS OF BEET-SUGAR WASTES ON THE QUANTITY, NUMBERS AND WEIGHTS OF FISH CAPTURED, CACHE la POUDRE RIVER, COLORADO, 1966. (TOTAL FOR 4 NET-DAY EQUIVALENTS.)

waste pollution. Downstream from the beet-sugar waste outfalls, the number of species present (Figure 32) was reduced from 77 to 100 percent in November compared to August. Beet-sugar wastes destroy or drive from the area those fish that cannot tolerate the polluted waters. Only two of the four affected sampling stations had any fish and these were a few white suckers and one specimen of the common shiner.

The numbers and weights were also drastically reduced (Figure 33). Whether the fish were killed or driven from the areas of poor water quality is open to conjecture. The data indicate that possibly some fish did escape; more fish were captured in November than in August in the cleaner waters upstream from beet-sugar waste outfalls, indicating that some fish may have escaped the intolerable conditions in the polluted reaches of the river. But, the fact remains that twenty-six miles of the river were not fit for propagation of fish, including the tolerant kinds.

Irrigated Crop-lands

Since large quantities of beet-sugar waste polluted waters are eventually used for the irrigation of crops, tests were undertaken to ascertain if any problems might be expected with irrigated crops common to the South Platte River Basin.

Germinating seeds are one of the most sensitive stages in the growth of plants (32). Seeds of alfalfa, corn, and sugar beets were subjected to bioassay germination tests. The moisture provided in these germination tests was from serial dilutions of waste water effluents from the beet-sugar mills at Longmont, Greeley, Eaton, and Windsor, Colorado. The results of these tests did not indicate any adverse effects of beet-sugar waste waters on germinating seeds.

Samples for examination for fungi were taken from the Cache la Poudre River during the autumn of 1964, and the summer of 1965 (33). Figures 34 and 35 summarize a portion of these results from samples collected in the lower reach of the river.

There was a general increase in the number of colonies of fungus isolated from sampling points downstream from sources of waste waters "With the addition to these sites of organic matter in the form of wastes of a variety of kinds, the populations of these organisms increase through use of these wastes as food materials, resulting in larger inocula for downstream areas. When waters containing such spores are added to fields with susceptible crops there is a potential hazard." (33). Increases in colony numbers occurred below the fish hatchery at Bellvue, the Fort Collins waste outfall, and the Windsor beet-sugar waste outfall. The increase in the number of colonies is especially obvious downstream from the beet-sugar waste water outfall during the autumn processing season. The increases occur in both the water samples and the bottom sediments which were essentially sludge

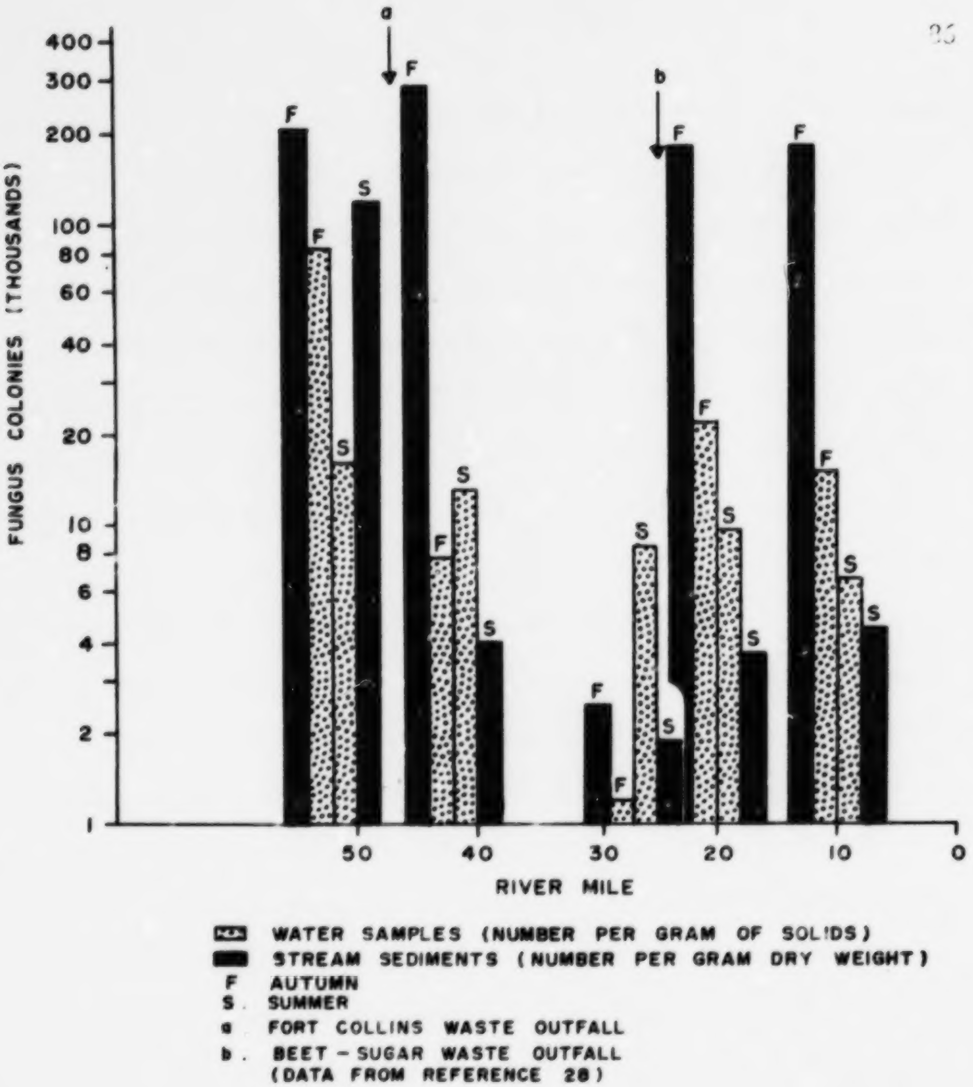

FIGURE 34. NUMBER OF FUNGUS COLONIES IN CACHE la POUDRE RIVER SAMPLES.

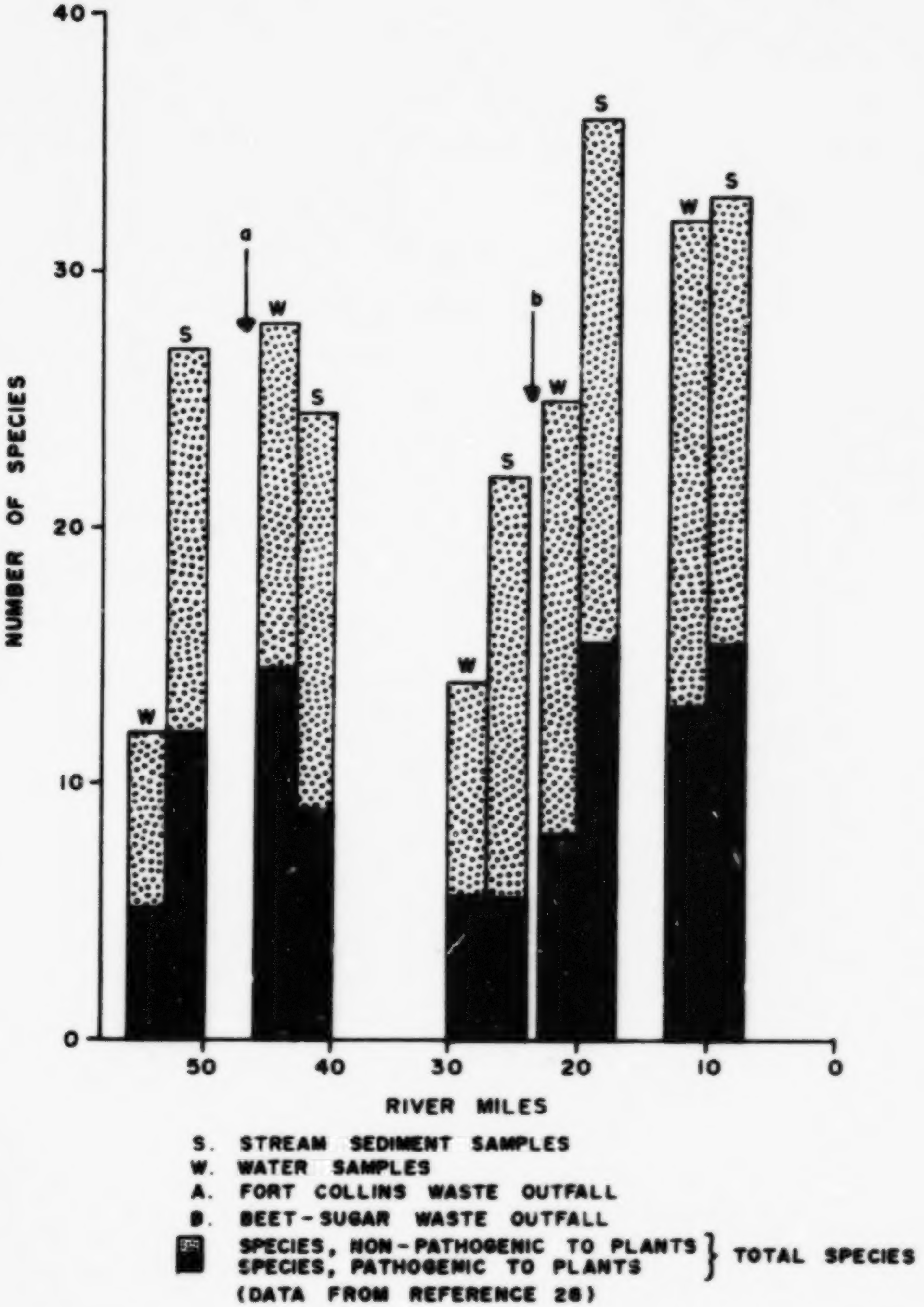

FIGURE 35. NUMBER OF SPECIES OF FUNGUS IN CACHE la POUDRE RIVER.

deposits containing decomposing sugar beet parts and soils washed from the beets.

More total kinds of fungus were also found downstream from waste sources than in other reaches of the stream. This increase in variety also included an increase in the number of kinds that are potentially pathogenic to plants.[*]

Mining

At the beginning of this century mining was Colorado's major industry. Today its value ranks fourth, having been superseded in the State's economy by manufacturing, tourism, and agriculture.

Mining activities, past and present, have left various kinds of marks in many areas of the mountains. The effect on waters has been long disregarded; these effects originate from several inherent factors associated with the nature of mining. Some of the factors are:

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[*] "Some of the species...............which can cause disease include: *Fusarium oxysporum*, *F. solani* and *F. roseum*, all capable of causing vascular wilt diseases or leaf spots on a variety of crop plants; a species of *Cephalosporium*, possibly represented here, can cause a severe disease of grasses and grains; species of *Rhizopus*, *Penicillium*, *Aspergillus*, *Aureobasidium* and other fungi listed can cause severe problems in the storage and shipment of various kinds of produce; *Alternaria tenuis*, species of *Stemphylium* and *Curvularia* and species of *Phoma* cause mild to serious infection in leaves and roots of some crop plants, or they may attack only the senescent leaves. Other fungi on the list cause damage of one sort or another to crop plants." (33).

1. Early mining was not subjected to controls. What controls were established came about only after needs became apparent, and after decades of accumulating neglect.
2. Mineral deposits were widely scattered resulting in a wide distribution of strikes, each of which was locally deemed more important than the protection of the surrounding environment. The net result has been widespread damage to the State's total environment.
3. Mining harvests a non-renewable resource and once the preempted mines were exhausted, the areas were abandoned as worthless by the proprietors. Consideration was not made for the future of the areas that after exhaustion of the mines became an economic liability subject to abandonment and return to the public domain.
4. Claims for mining rights give title to the mineral resources but do not carry stipulations for the protection of other resources in the environment.
5. For economic reasons, claims may be abandoned. The abandoned claim may be re-claimed by a new proprietor. This may have occurred many times in areas with low-grade

mineral deposits. Existing damages may have resulted from someone other than the present responsible individuals.

6. The age of origin of many of the mine associated pollutants, or conditions conducive to polluting, is such that original owners are deceased and companies have been dissolved.
7. Changes in economic conditions create alternate periods of accelerated and declining exploitation, thereby producing fluctuating demands on the agencies with authority.
8. Increased national armament during periods of accelerating hostility or war encourages immediate exploitation of vital minerals. To encourage the fulfillment of the immediate need, restrictions for the less obvious long-term protection of the environment are often relaxed.

The net result has been the development of widespread long-existing conditions conducive to the pollution of waters, and the establishment of a situation whereby responsibilities are not delegated nor assumed.

Because of the wide geographical coverage of mining activities and the numerous sources of pollution, biological field investigations were undertaken in only three exemplary areas. These areas are as follows:

Geneva Creek Basin - tributary to the North Fork of the South Platte River near the community of Grant.

Clear Creek Basin - the mountainous upstream portion west of Golden, including the communities of Silver Plume, Georgetown, Empire, Idaho Springs, and Central City.

Mosquito Creek Basin - tributary to the Middle Fork of the South Platte River near the community of Alma.

These three basins are high altitude, in the mineral belt, and have a long history of mining activity.

Geneva Creek Basin

Geneva Creek is a fourteen mile long stream, originating in a 12,000 foot high cirque. It has several tributaries, principal of which are: Smelter Gulch, Duck Creek, Bruno Gulch, and Scott Gomer Creek (Figure 36). Historically the basin has produced some precious metals, and bog-iron ore (limonite) that was used at small local smelters to produce mining tools. Recently a large deposit of bog-iron located near the head of Geneva Creek has been exposed by stripping off the over-burden preparatory to strip mining. During the study ore removal had not begun, but considerable drainage from exposed seeps was entering the stream and polluting it.

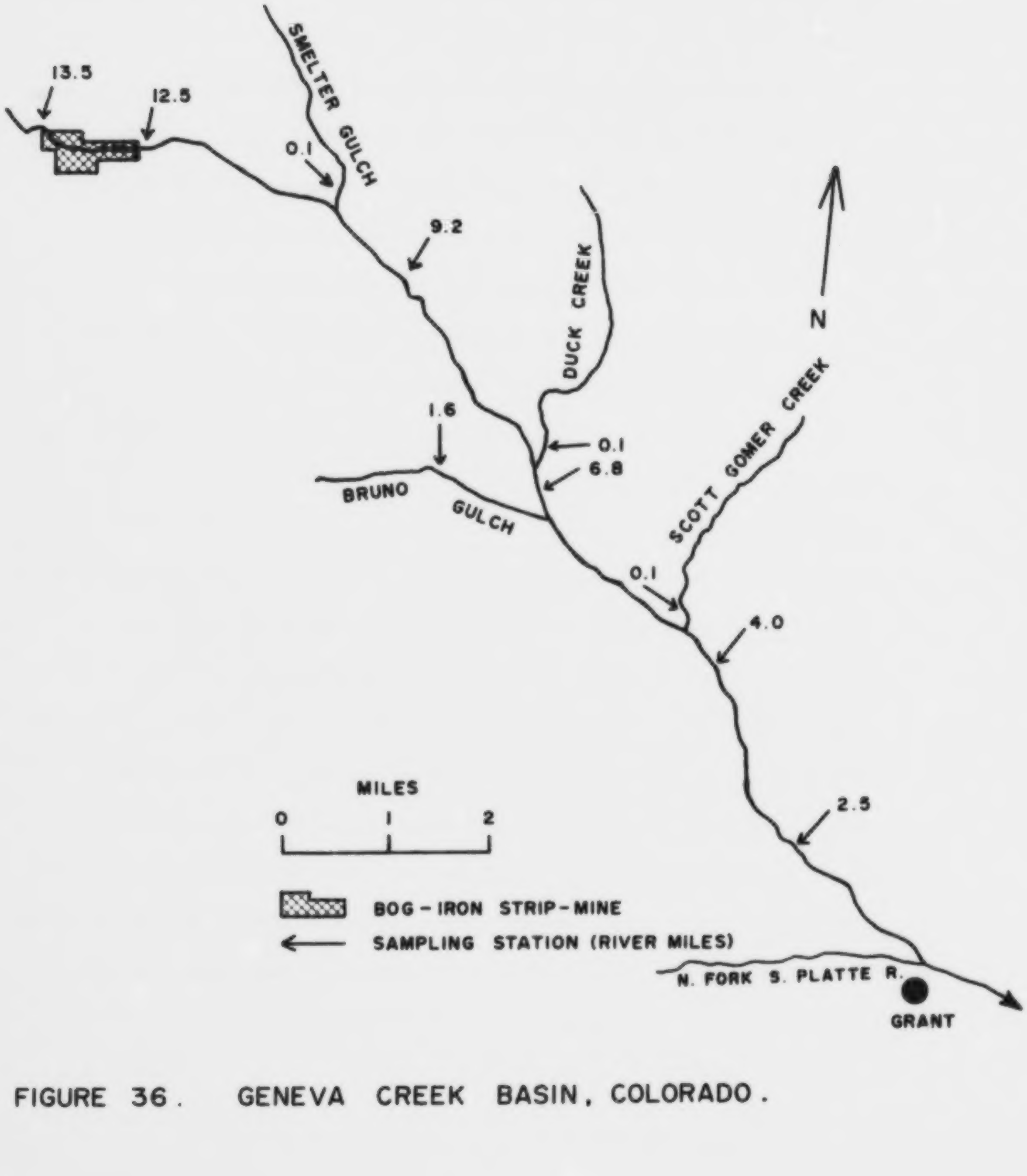
13.5
12.5
SMELTER GULCH
0.1
9.2
DUCK CREEK
N
SCOTT GOMER CREEK
1.6
0.1
6.8
BRUNO
GULCH
0.1
4.0
MILES
0
1
2
2.5
BOG - IRON STRIP-MINE
SAMPLING STATION (RIVER MILES)
N. FORK S. PLATTE R.
GRANT

FIGURE 36. GENEVA CREEK BASIN, COLORADO.

Acidity and iron leached from the exposed iron deposits are the primary damaging pollutants. The largest single source of acidity in the Geneva Basin is mine drainage (Figure 37). The tributary Scott Gomer Creek carries a large quantity of acidity, but the acidity is counteracted by an accompanying large quantity of alkalinity. The mine discharges carry no alkalinity to neutralize the acidity discharged.

The mine drainage is also the largest single source of water borne iron (Figure 38). Scott Gomer Creek transports a large quantity of iron, but the Creek's large volume of water dilutes the iron to an acceptable concentration for the propagation of aquatic life.

Concentrations of acidity, and iron in mainstream and in the tributaries are illustrated in Figure 38. All of the major tributaries supported trout; and it was not until all of these tributaries had added water to dilute and reduce the iron and acid concentrations in the mainstream that Geneva Creek was capable of supporting fish life. Figure 39 illustrates the effects of dilution by tributary originating waters on the quantities of acidity and alkalinity, and the resulting pH of the waters. Not until after the river had flowed 5.5 miles and passed its second major tributary confluence was the acidity sufficiently diluted and reduced by reaction with inflowing alkalinity to permit a quantity of alkalinity to remain in the water. Alkalinity is required by most organisms because of the vital buffering

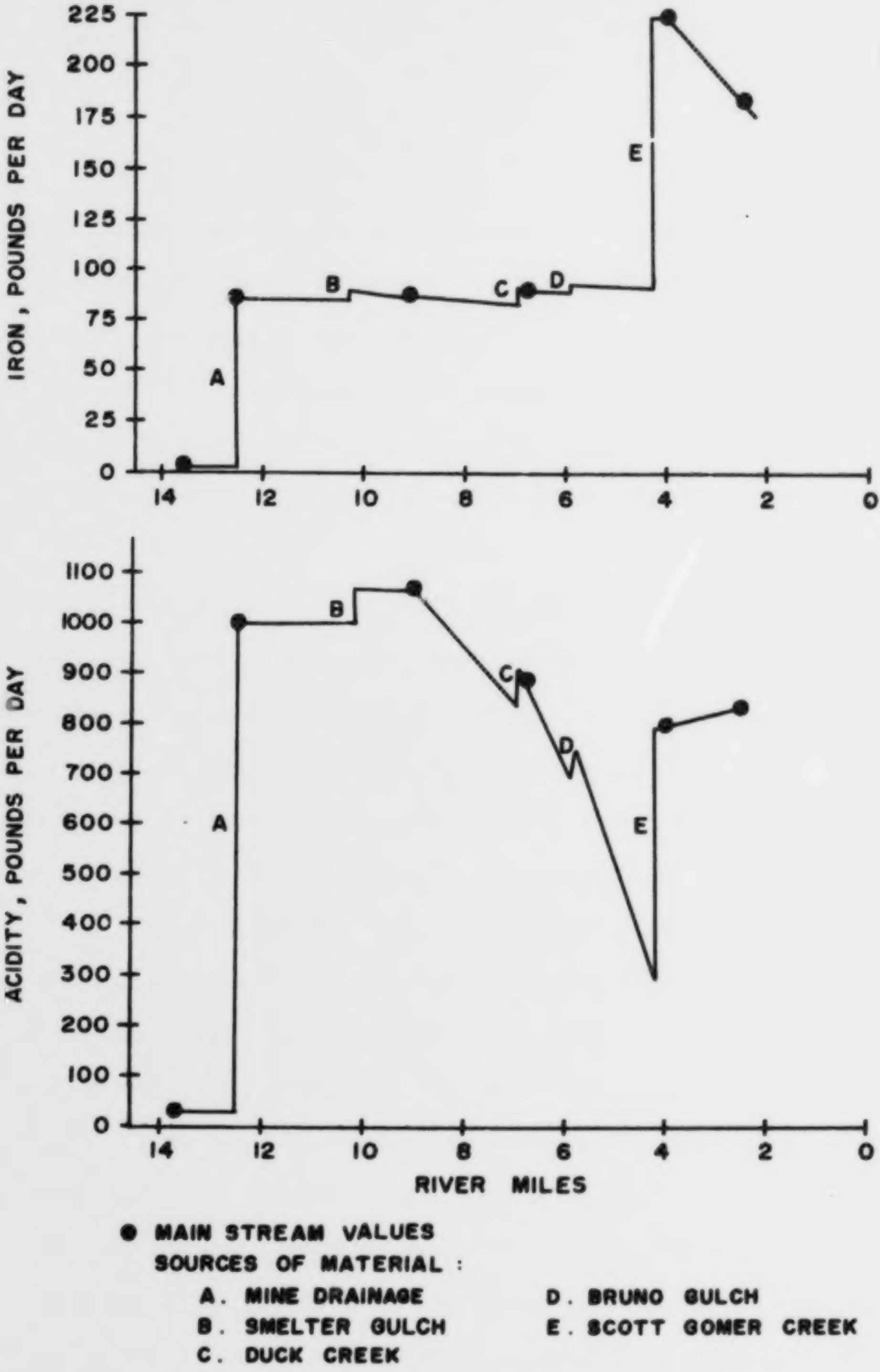

FIGURE 37. THE QUANTITY AND SOURCES OF IRON AND ACIDITY IN GENEVA CREEK, COLORADO, 1966.

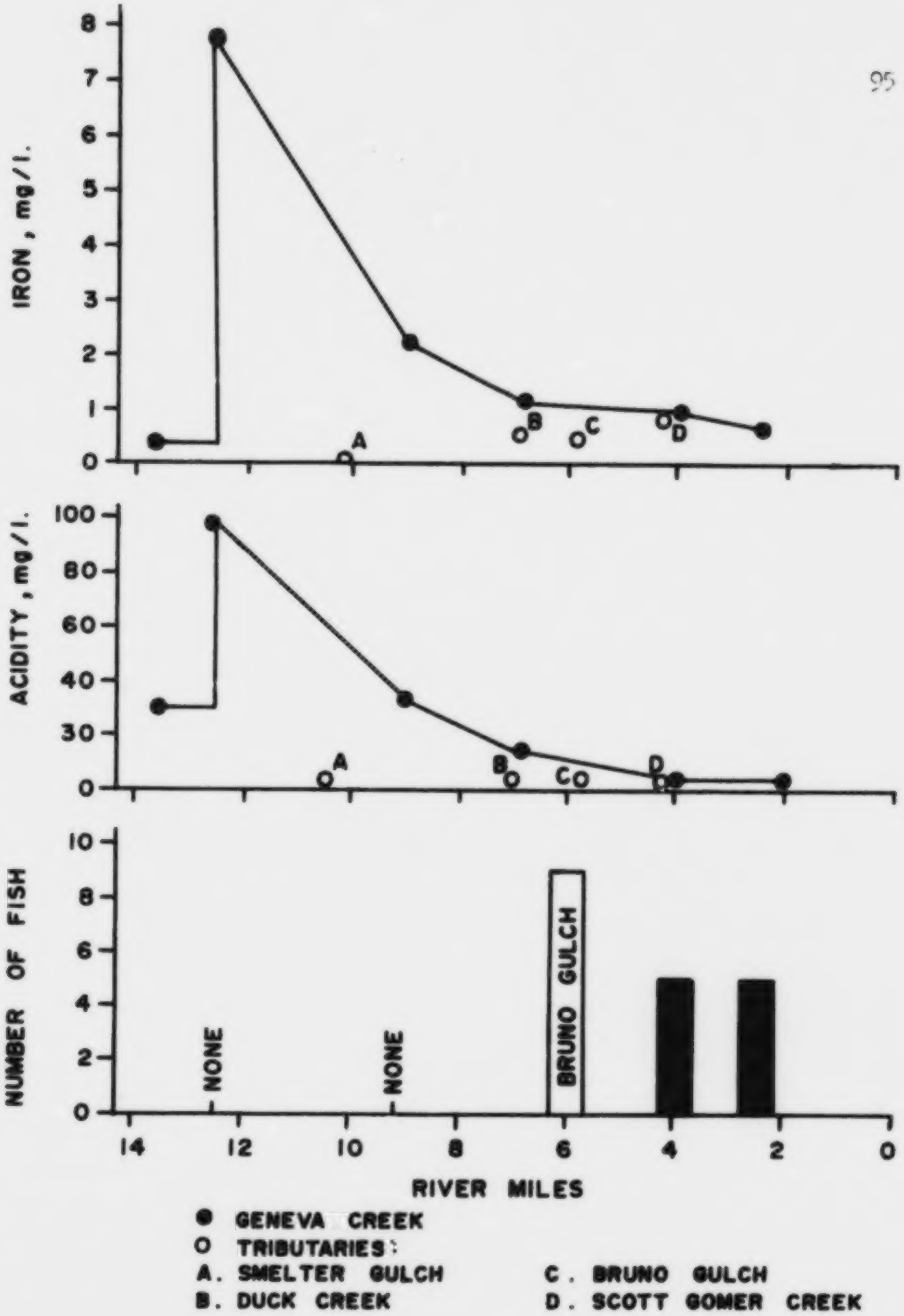

FIGURE 38. THE CONCENTRATIONS OF IRON, AND ACIDITY, AND THE NUMBER OF FISH CAPTURED, GENEVA CREEK AND TRIBUTARIES, COLORADO, 1966.

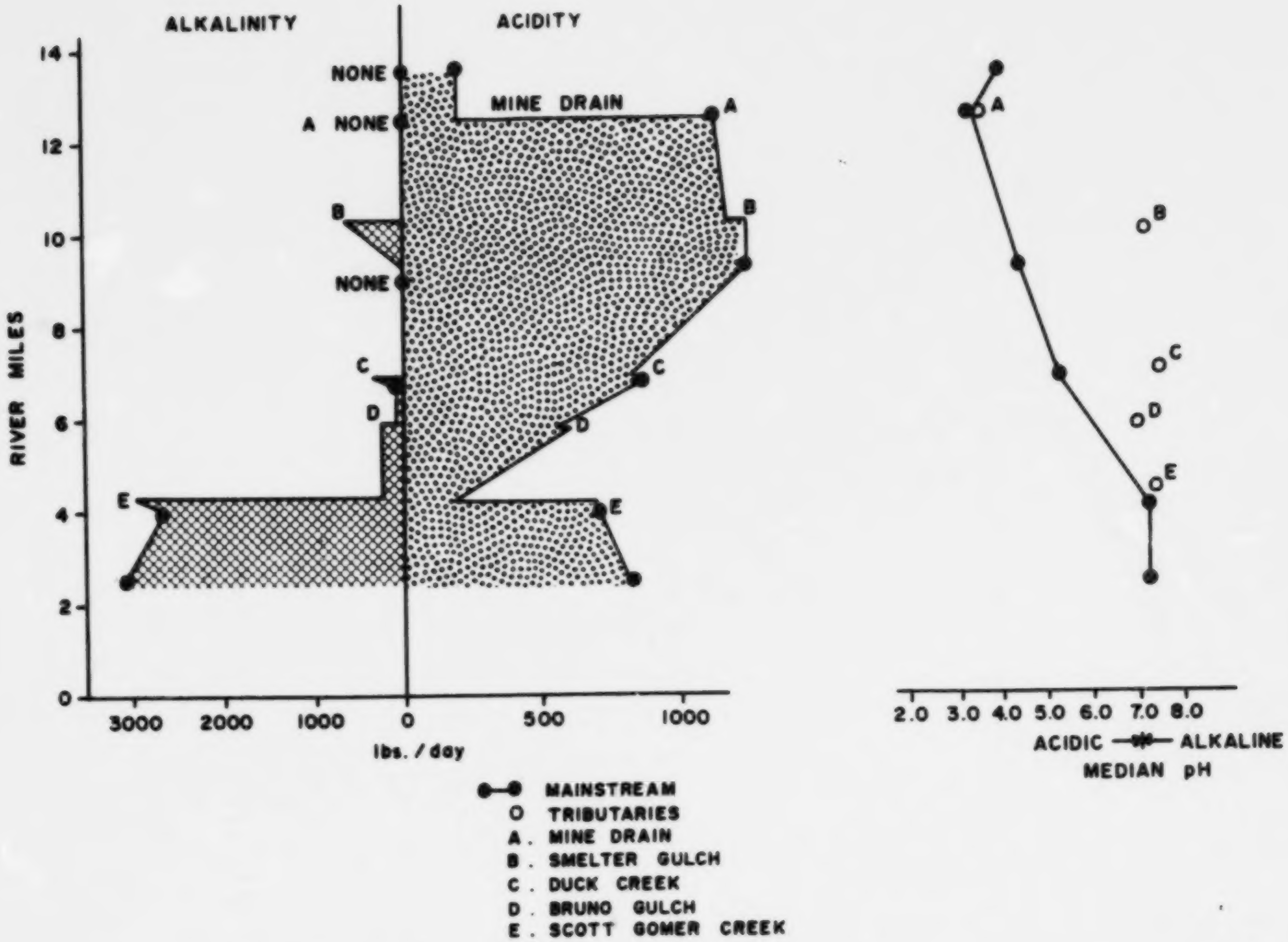

FIGURE 39. QUANTITIES OF ALKALINITY, ACIDITY AND pH IN GENEVA CREEK AND TRIBUTARIES, COLORADO, 1966.

role it plays in the organism's physiological systems. The water's pH, also shown in Figure 39, is a function of the interaction between acidity and alkalinity fractions in the water. The lower tolerable pH limit for most aquatic organisms is about 4.5 (34), because at pH values lower than this the high acid ion concentration rapidly destroys the alkalinity in water.

On the basis of pH and alkalinity, trout should live in the reach downstream from the confluence of Duck Creek (river mile 6.9), but they do not survive in the stream until after it has flowed past the confluence of Scott Gomer Creek (river mile 4.3). Iron is the limiting agent in the intermediate stream reach, and its concentration remains toxic until diluted by water from Scott Gomer Creek. Iron is toxic beginning at a concentration near 1 mg/l in soft and acid waters such as occur in the Basin (29). These data from laboratory observations agree with values observed in the field; the highest mean iron concentration in which trout were observed was 0.93 mg/l.

Mine pollution not only eliminated trout, but it also had adverse effects on the food-chain of algae and bottom animals that support fish populations (Figure 40). Part of the effect on these organisms is also a result of toxicities, but consideration must also be made of the precipitation of iron that in the upper stream reaches covers the entire stream bed with iron oxide deposits. These deposits destroy plant and animal life by burial of organisms with precipitates, and

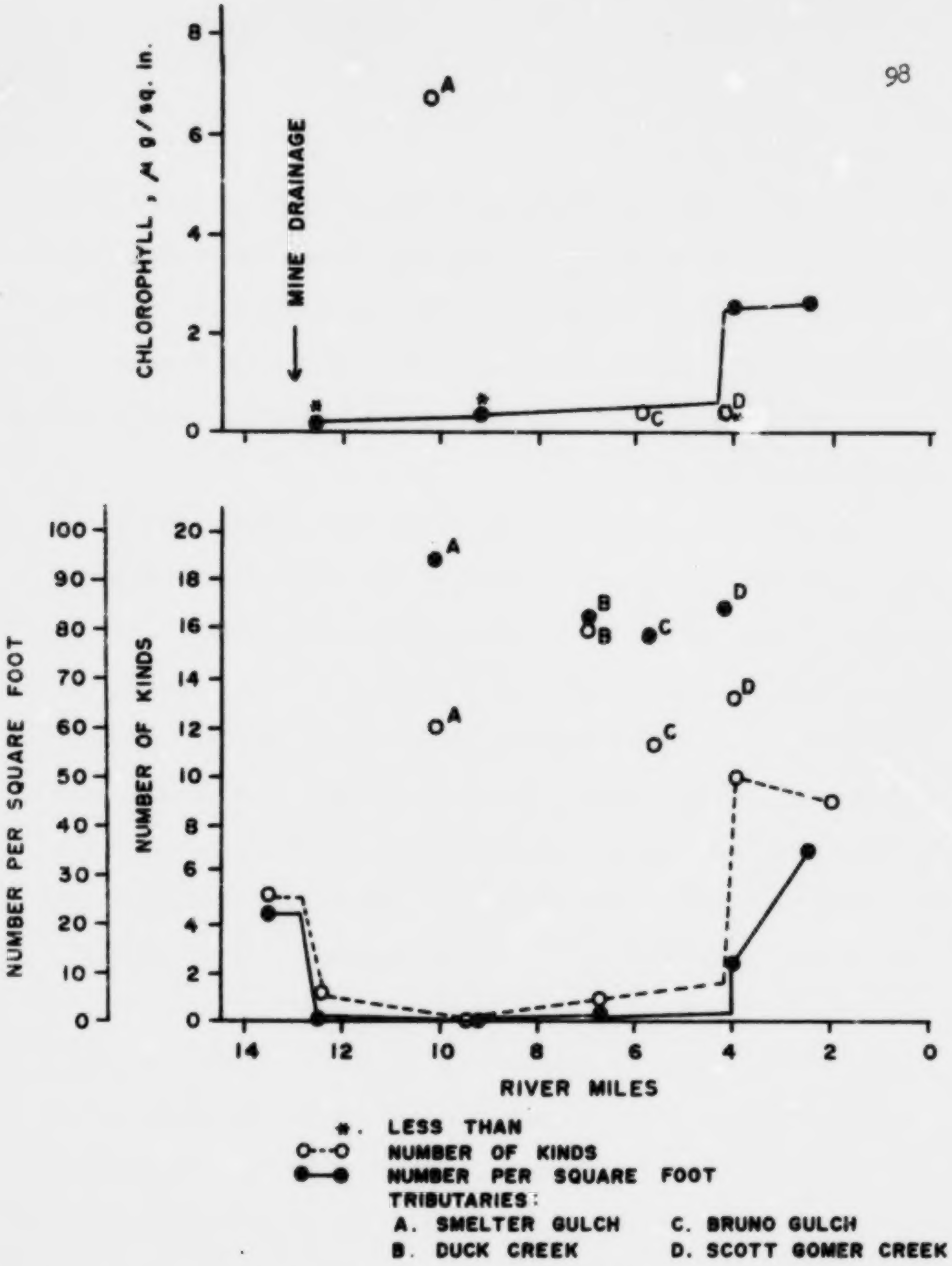

FIGURE 40. EFFECTS OF MINE DRAINAGE ON ALGAL GROWTH, (AS CHLOROPHYLL), AND ON THE NUMBER AND NUMBER OF KINDS OF BOTTOM ANIMALS, GENEVA CREEK AND TRIBUTARIES, COLORADO, 1966.

alter the habitat thus interfering with the hatching of eggs, attachment of organisms to the bottom, and feeding activities.

Much of Geneva Creek could be salvaged through pollution abatement measures. A portion of the extreme upper reach may not be subject to remedial action because of the high natural concentration of acid. It would be especially desirable to salvage the stream upstream to the confluence of Smelter Gulch (river mile 10.3). This would add six miles, 140 percent, to the mainstream fish producing waters. Recovery of these waters would be extremely desirable because the area would include most of the physically excellent and desirable fishing portion of the waterway, the area is on public lands readily accessible and already developed with recreational sites by the Forest Service, and the area is close to metropolitan population centers that are in need of increasing recreational sites.

Reclamation of the waterway will require a 65% reduction in the quantity of acidity and iron discharged by the bog-iron mine to the stream. This would lower the concentration of pollutants in the mainstream at the confluence of Smelter Gulch to a level whereby, after addition of low iron and acidity and high alkalinity bearing waters from the tributary, the concentrations in the mainstream would be tolerable for the propagation of trout.

The method of achieving a 65 percent reduction in mine drainage would be subject to economic and engineering studies made by the mining interests and the State. Proposals should involve diversion of water around the deposits thereby reducing the volume of water percolating through the deposit. Considerations might involve accelerated mining activities to remove the deposit in the shortest possible time, and then stabilization of the mined area with diversion of seepage and surface waters from the unrecoverable residual ore.

Clear Creek Basin

The upper portion of the Clear Creek Basin (Figure 41) covers a relatively large area compared to many of the mountain drainage areas in the South Platte River Basin. Clear Creek has experienced a long history of mining activity at many locations within the basin. Some of the earliest and richest strikes were made in this watershed, and several communities developed around these strikes. After exhausting the mines, these communities were on the verge of becoming ghost towns. Today they are making an economic recovery by catering to tourism and recreation. The principal role of mining in many of these communities is its historical aspect that serves as a tourist attraction, as evidenced by active efforts to preserve and restore large portions of communities, such as Georgetown and Central City, to resemble their nineteenth century state.

Today in the Basin, active mining consists principally of limited placer mining (a portion serving as tourist attractions) along North Clear Creek, reprocessing of old tailing piles at Silver

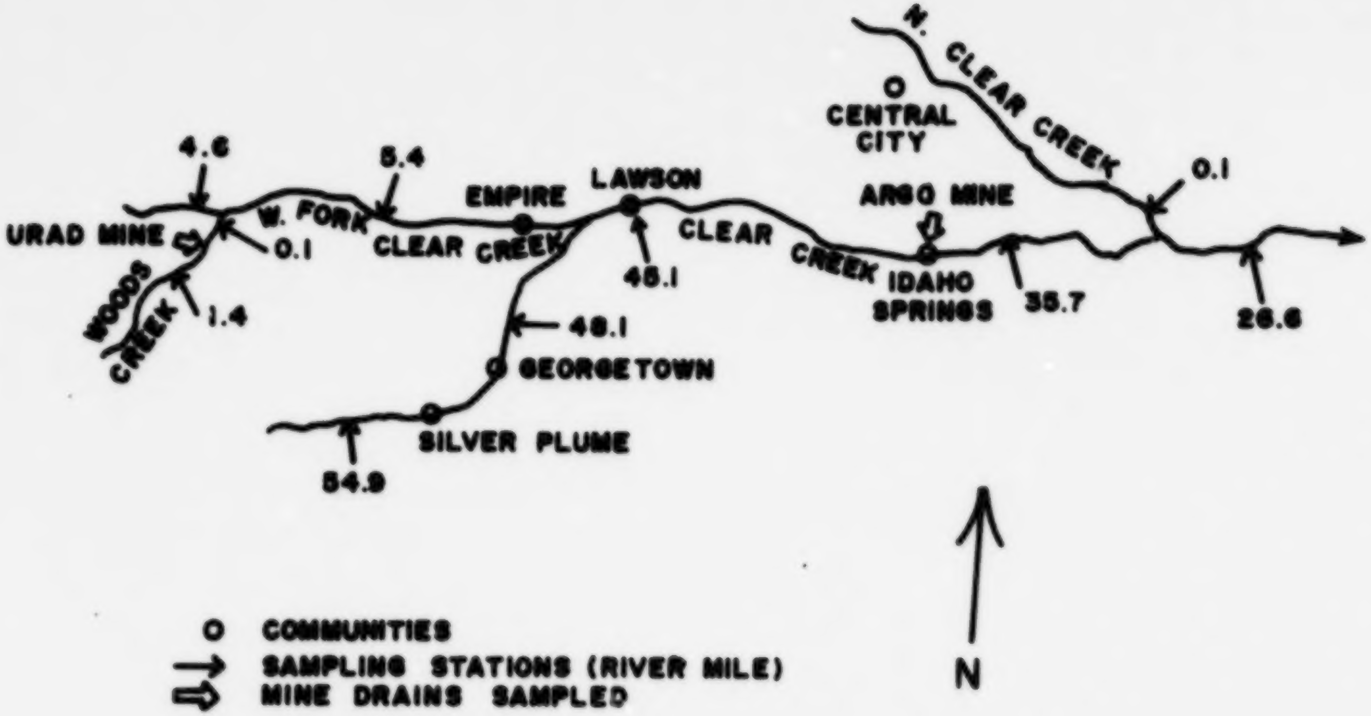
N. CLEAR CREEK
CENTRAL CITY
4.6
5.4
EMPIRE
LAWSON
0.1
ARGO MINE
URAD MINE
W. FORK
0.1
CLEAR CREEK
CLEAR CREEK
WOODS CREEK
1.4
45.1
IDAHO SPRINGS
35.7
26.6
48.1
GEORGETOWN
SILVER PLUME
54.9
N
○ COMMUNITIES
→ SAMPLING STATIONS (RIVER MILE)
⇨ MINE DRAINS SAMPLED

FIGURE 41. CLEAR CREEK BASIN, COLORADO.

Plume, a small mining and milling operation at Central City, the Urad molybdenum mine near the headwaters of the West Fork of Clear Creek and Berthoud Pass (at the time of survey the Urad mine was being opened; ore production had not started). Inactive mines, mills, old tailings piles, and other remnants of mining are widely scattered throughout the basin. Dense concentrations of mining remnants occur in the Georgetown - Silver Plume area, at Idaho Springs, and in the Blackhawk - Central City area.

Water seepage through the widely scattered tailing piles dissolves minerals and acids that eventually drain to the waterways. Many mine tunnels discharge large quantities of heavy metals and acids to the streams. The net result is damage to the aquatic life of the Basin's streams. Excellent highways make this area readily accessible to recreationists, and any damage to the fisheries of these streams is a direct loss to these tourist- and recreation-oriented communities.

The acids discharged to the streams are of minor importance in most areas. The Basin's surface waters contain sufficient quantities of alkalinity to neutralize the acids and maintain the pH of the water near neutrality.

The heavy metals discharged to the streams are significant. Concentrations of iron, lead, and zinc exceed or approach levels that have been reported as toxic to aquatic life. In some areas the biota indicated toxic effects when the concentrations of a single kind of heavy metal were not at a high enough level to be suspected as a toxicant, thus suggesting that two or more heavy metals were acting in combination to effect toxicity.

The data on metals that were at abnormally high concentrations and approached the reported level of toxicity were submitted to a recently reported method (35) of data analyses in which the metals concentrations are adjusted for their relative toxicity and the adjusted values are added together:

$$F = \frac{C_1}{T_1} + \frac{C_2}{T_2} + \frac{C_3}{T_3} + \ldots\ldots\ldots \frac{C_n}{T_n}$$

Where: C = concentration of material in the stream

T = threshold toxicity of this material

and, F = fraction of the toxicity threshold.

The toxicity threshold (F) of the mixture of several toxicants is considered as 1.0. It is necessary to use this method because of varying relative toxicities of different heavy metals. For example, in soft, low-alkalinity waters the toxicities of lead, zinc, and iron to fish are respectively 0.1, 0.5, and 1.0 mg/l. With this method it is also possible to estimate the quantity of reduction required to reduce materials to a tolerable concentration. To reduce the toxicity of a solution containing a mixture of heavy metals, the removal of the more toxic metal will achieve the greatest effect, i.e., the removal of lead will have ten times the effect of that achieved by removal of an equal quantity of iron. To check the method's validity in Colorado, all fish collected in all mining affected basins were compared to the net toxicity threshold (F) values for these fish-sampling stations. The summarized results follow:

	Percent	
	Waters With Threshold Toxicity Value Less Than 1.0	Waters With Threshold Toxicity Value Greater Than 1.0
Sampling Stations	58	42
Fish Captured	91	9

In addition, over half of the fish collected at a threshold toxicity greater than 1.0 were from a station located 1 mile downstream from Georgetown (F = 1.2). The water at this station contained large quantities of recently discharged untreated municipal sewage as evidenced by the chopped garbage and fecal material suspended in the water. Organic solids can absorb metals (36) thereby reducing their effects.

Most of the mainstream of Clear Creek contained waters that were toxic to fish. The fish populations were nearly, or actually decimated in many reaches (Figure 42). Three heavy metals, iron, zinc, and lead, were the principal toxic components discharged by mine drainage; other heavy metals were at concentrations that were too low to be considered as having significant effects. The quantities of zinc, lead, and iron transported by the stream, along with

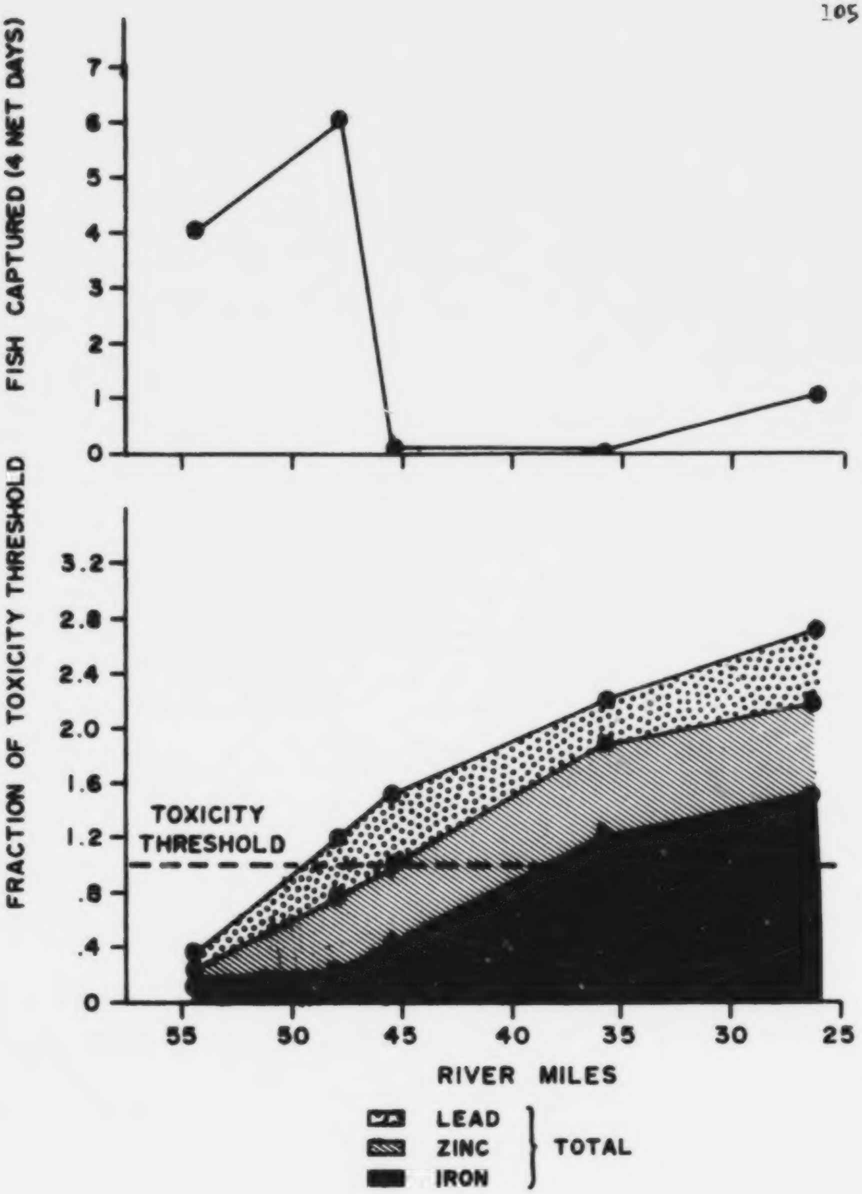

FIGURE 42. TOXICITY OF WATERS AND FISH POPULATIONS IN CLEAR CREEK, COLORADO, AUGUST 1966.

some of the sources and the quantities discharged by them are illustrated in Figure 43. It is obvious that some sources were not measured. These unmeasured sources were also primarily from mine drainage because the unmeasured volume of water entering the stream was small, and the concentration of metals in these influents had to be very high to bring about the increases in concentrations observed in the large volume of river water. Table 1 contains estimates of the quantities of iron, zinc, and lead from measured sources and by river reach that were discharged to the mainstream during August, 1966.

The attached algae in Clear Creek were found to be more tolerant of the metals than were the fish. After the addition of wastes, especially domestic wastes, the number of attached algal cells, and the quantity of chlorophyll increased (Figure 44). This is an apparent response to an increase in nutrients and is most evident on the mainstream of Clear Creek. For example, the mean total phosphorus concentrations increased from less than 5 µg/l to 28 µg/l downstream from Georgetown after which algal uptake reduced concentrations until wastes from Idaho Springs again increased the concentrations in the stream to 40 µg/l with subsequent reduction downstream by uptake of phosphorus by the biological community. Nitrogen concentrations were very low; the minimum detectable concentration (210 µg/l total nitrogen) was not consistently exceeded until after the stream had flowed past Idaho Springs.

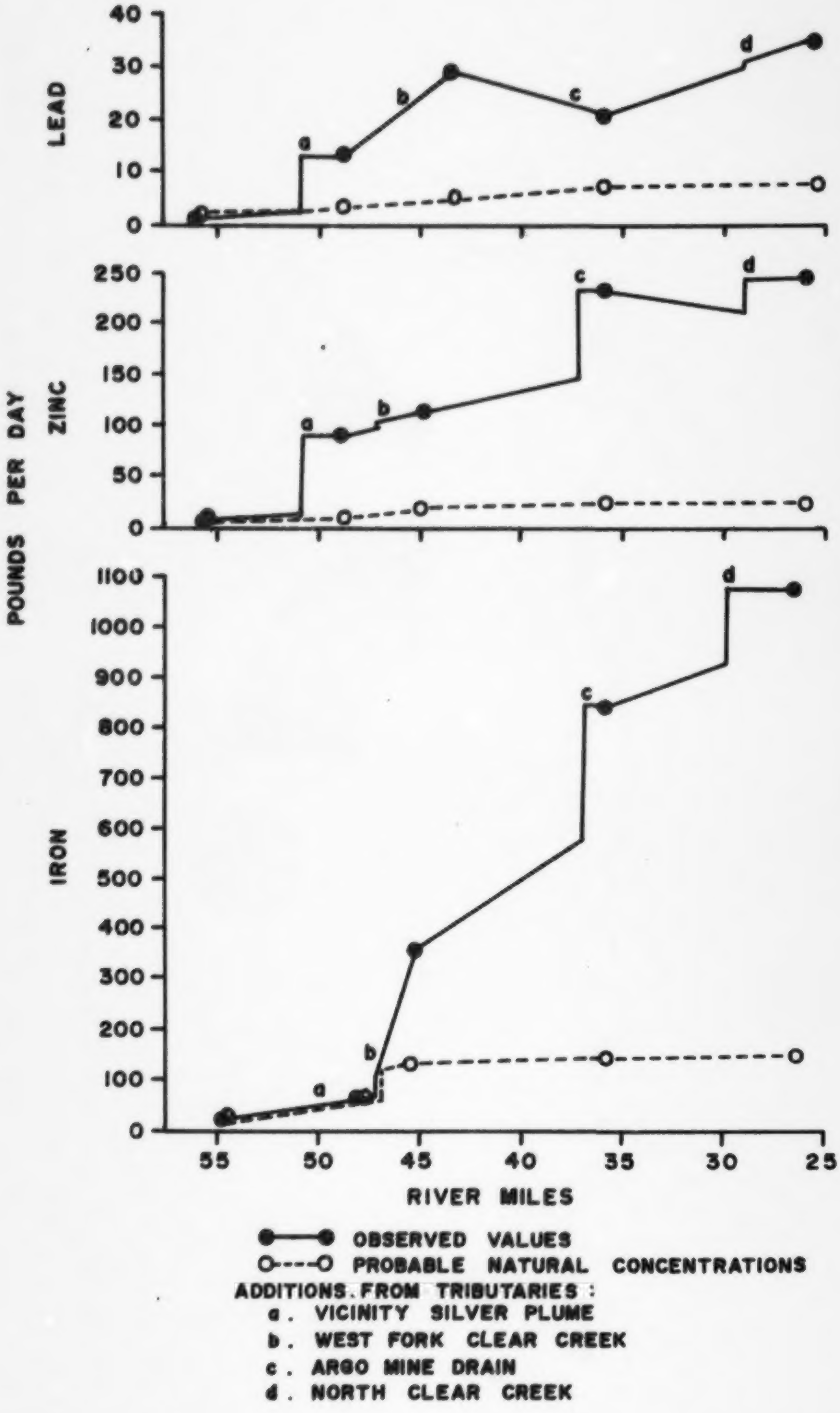

FIGURE 43. THE QUANTITIES OF LEAD, ZINC, AND IRON TRANSPORTED BY CLEAR CREEK, COLORADO, AUGUST 1966.

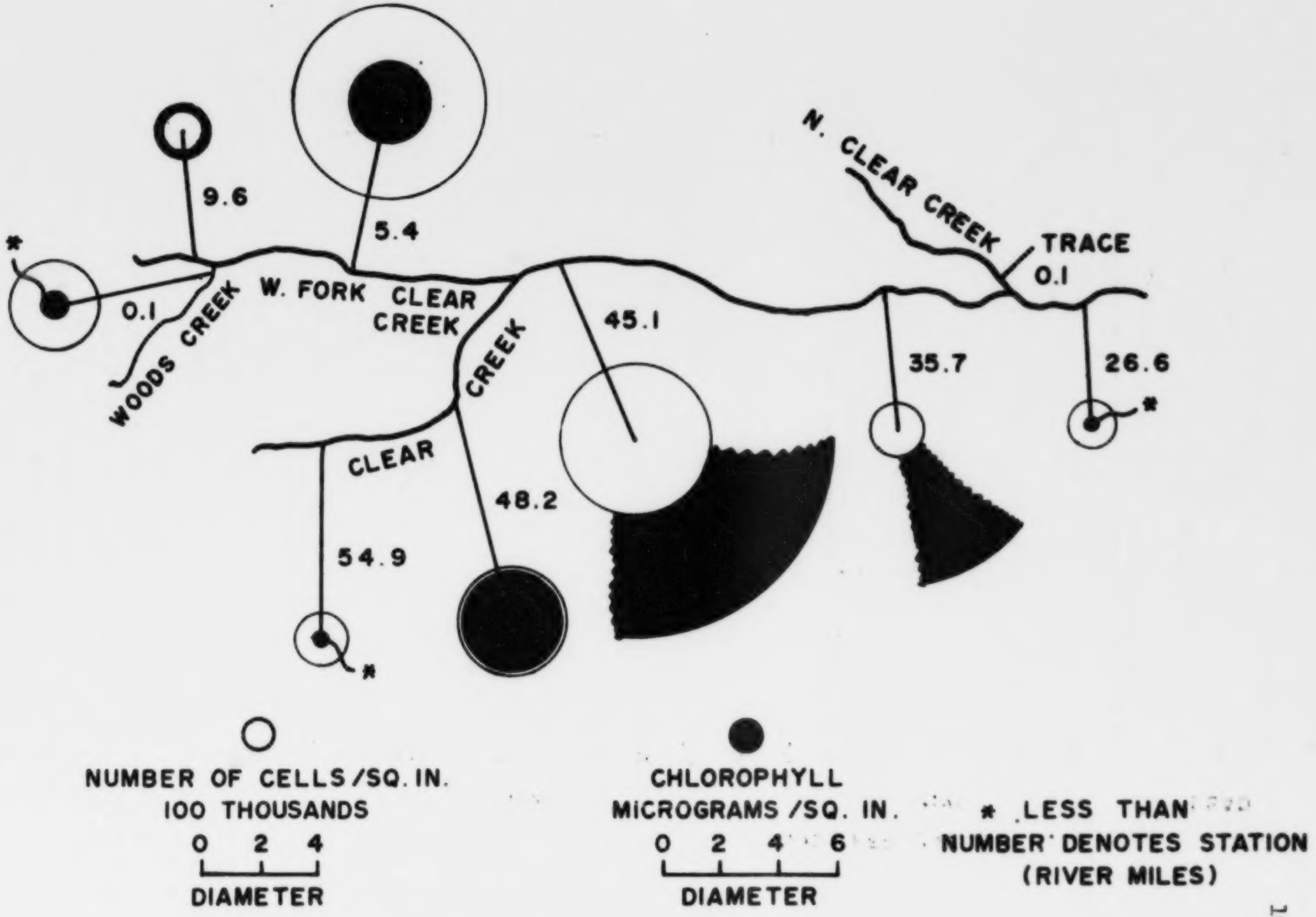
N. CLEAR CREEK
TRACE
0.1
26.6
*
35.7
45.1
5.4
9.6
0.1
*
WOODS CREEK
W. FORK CLEAR CREEK
CREEK
CLEAR
48.2
54.9
*
NUMBER OF CELLS/SQ. IN.
100 THOUSANDS
0 2 4
DIAMETER
CHLOROPHYLL
MICROGRAMS/SQ. IN.
0 2 4 6
DIAMETER
* LESS THAN
NUMBER DENOTES STATION
(RIVER MILES)

FIGURE 44. ATTACHED ALGAE, CLEAR CREEK, COLORADO, AUGUST 1966.

Table 1. Estimated Quantities[1] of Heavy Metals
Discharged to Clear Creek, Colorado
August 1966[2]

River Reach	Pounds Per Day		
	Iron	Zinc	Lead
Vicinity of Silver Plume[3]	Trace	80	9
Georgetown to Lawson (River Mile 48.1 to 45.1):			
West Fork Clear Creek	40	2	Trace
Other Source(s)	200	18	12
Lawson through Idaho Springs (River Mile 45.1 to 35.7):			
Argo Mine Drain	285	83	Trace
Other Source(s)	200	33	Trace
Downstream from Idaho Springs to Downstream from North Clear Creek (River Mile 35.7 to 26.6):			
North Clear Creek	142	29	Trace
Other Source(s)	Trace	Trace	14

1. Quantities are in addition to the estimated natural quantities that would be expected. The clean waters of the Basin contained 0.2 mg/1 of iron, 0.02 mg/1 of zinc, and 0.01 mg/1 of lead.

2. Underlined values were considered as significant waste quantities that should be subject to abatement. These values were used in projections to determine the effect of heavy metal removal on the toxicity of the stream waters (Figure 46).

3. Periodic sampling by the South Platte River Basin Project revealed this source was upstream from Georgetown.

Algae are adversely affected in North Clear Creek; this is probably the result of a combination of factors such as heavy metals (threshold toxicity exceeded 10.0), turbidity (up to 126 units), and suspended solids (mean, 41 mg/l). The last downstream station sampled on Clear Creek (below the confluence of North Clear Creek) had a relatively impoverished algal flora; the standing crop of algal cells was not exceptionally low, but low chlorophyll concentrations indicated a low rate of growth even though the nutrient concentrations were similar to those observed further upstream where growth was rapid as evidenced by the abundant chlorophyll. Some sedimentation was observed here and the toxicity threshold (2.7) was the highest observed in the mainstream. In much of the Clear Creek Basin algal growths were not adversely affected. The nutrients discharged were not harmful and actually would be an asset to the waterway by increasing the basic production of fish food. Any stimulus to the recreational fisheries that would result from the nutrients in untreated domestic waste waters were negated by other components of the waste waters such as the garbage, feces, and bacteria that impose aesthetic restrictions and health hazards on the use of these waters for recreation.

Plant material in a stream is converted to animal tissue by the bottom animals that then serve as animal food for the predatory fish such as trout, bass, etc. Headwater streams in the Clear Creek

Basin support very few bottom animals which is a reflection of the short supply of basic plant foods. Notably absent, or in very low numbers, were the caddisfly larvae that net their food from overpassing waters. With the addition of nutrients further downstream, both the quantity and variety of bottom animals increased (Figure 45). The increase in quantity is a response to the increased quantity of available algal food. The increase in animal variety was an anomaly: the number of kinds was probably as large or larger at Station 54.9 than at Station 48.2, but the scarcity of algal feeders, such as caddisfly and midge larvae, precluded their capture at Station 54.9 with routine sampling procedures. Downstream from Georgetown, the variety of bottom animals gradually decreased as the toxicity thresholds increased. This decrease in variety was the result of the elimination of the more sensitive forms. The number of animals also decreased, indicating an interference in the animal communities' utilization of available foods. At the last downstream sampling station (26.6), the numbers of organisms increased, but this increase was attributable to a few tolerant kinds of animals which were present in large numbers because of the elimination or reduction in number of the more sensitive competitive and predaceous animals of the bottom community.

Pollution abatement and ultimate restoration of the fisheries in Clear Creek will be necessary for future continued growth and

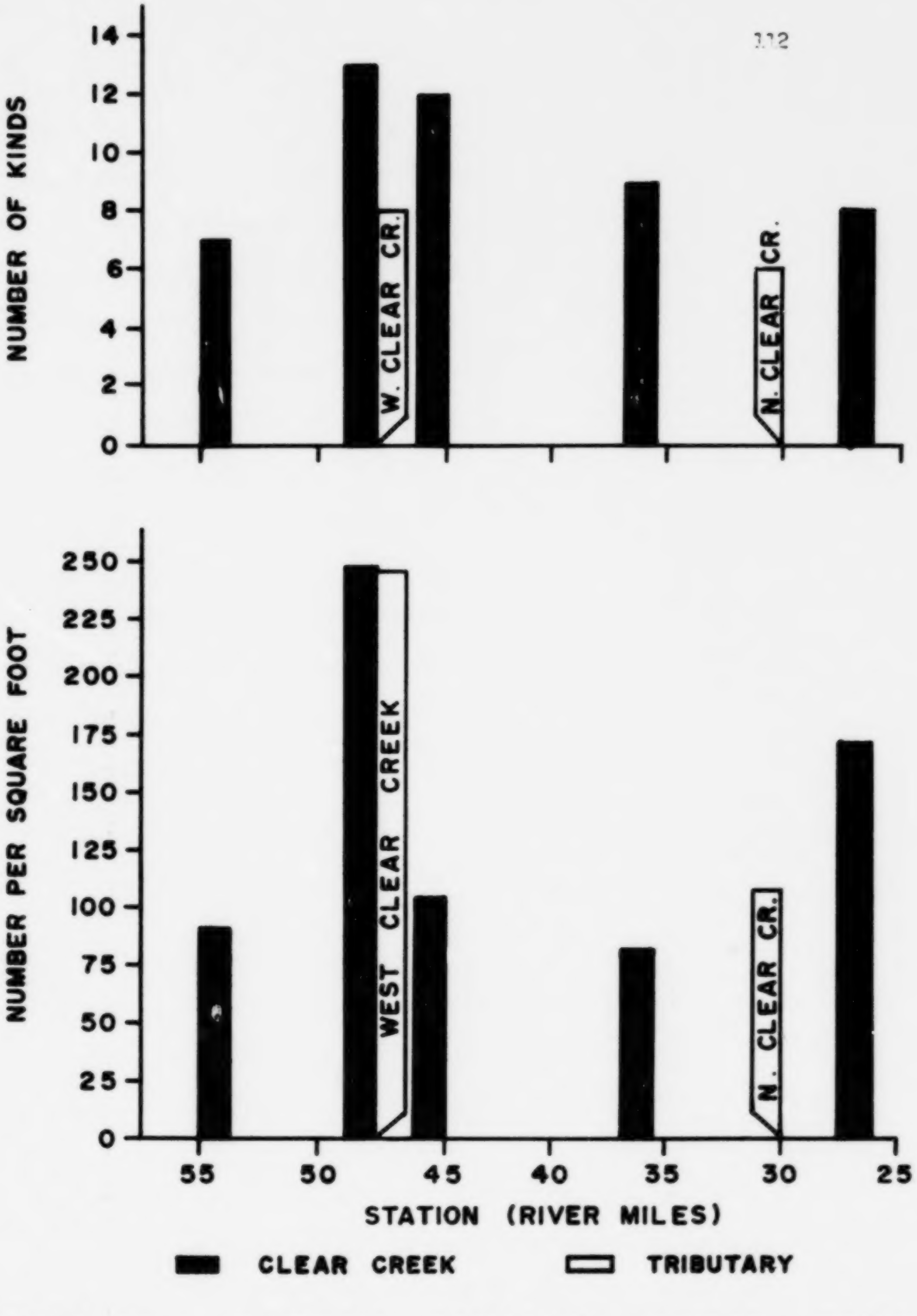

FIGURE 45. BOTTOM ANIMALS, CLEAR CREEK, COLORADO, AUGUST 1966.

expansion of the recreational industry in the Basin. The prime consideration for restoration of the fisheries is the reduction in quantity of heavy metals, especially lead, zinc, and iron, discharged by mining waste waters to the waterways. The estimated percentage reductions of heavy metals discharged that will be required to alleviate toxic conditions are illustrated in Figure 46. Estimates based on a 75 percent reduction of heavy metals indicate that toxic conditions would be alleviated in only a portion of the stream, and downstream from Idaho Springs the water's toxicity would fluctuate very near the toxicity threshold, a condition that would not be conducive to the sustained propagation of fish. A 90 percent reduction in quantity of heavy metals in mining discharges will be required to make the mainstream of Clear Creek acceptable for fish propagation. The 90 percent reduction would provide a 0.2 safety margin before the toxicity threshold would be reached. Such a safety margin will be required to safeguard the stream during periods when the volume of flow is reduced.

Mosquito Creek Basin

Mosquito Creek is an 8-mile-long stream that joins the Middle Fork of the South Platte River near Alma, Colorado (Figure 47). The creek has one major tributary, the South Fork of Mosquito Creek. This tributary and the upper mainstream drain watersheds respectively south and north of London Mountain. London Mountain contained large

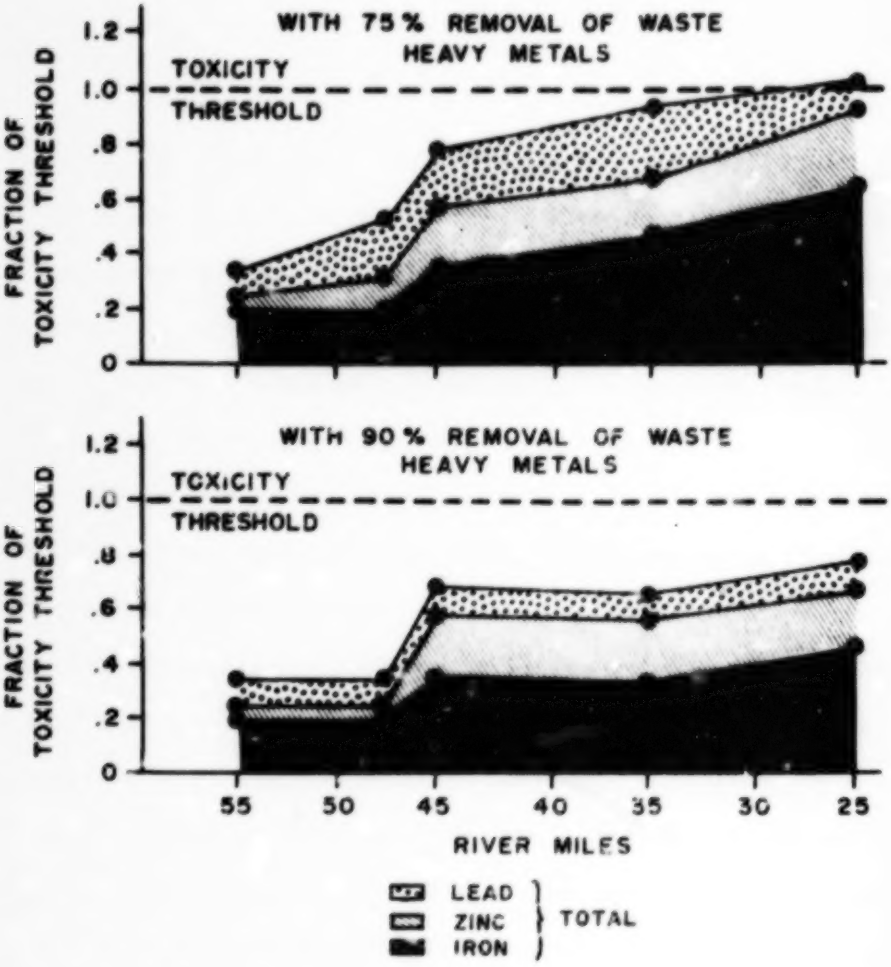

FIGURE 46. ESTIMATES OF THE EFFECT OF REDUCTION OF HEAVY METALS ON THE TOXICITY OF WATERS IN CLEAR CREEK, COLORADO.

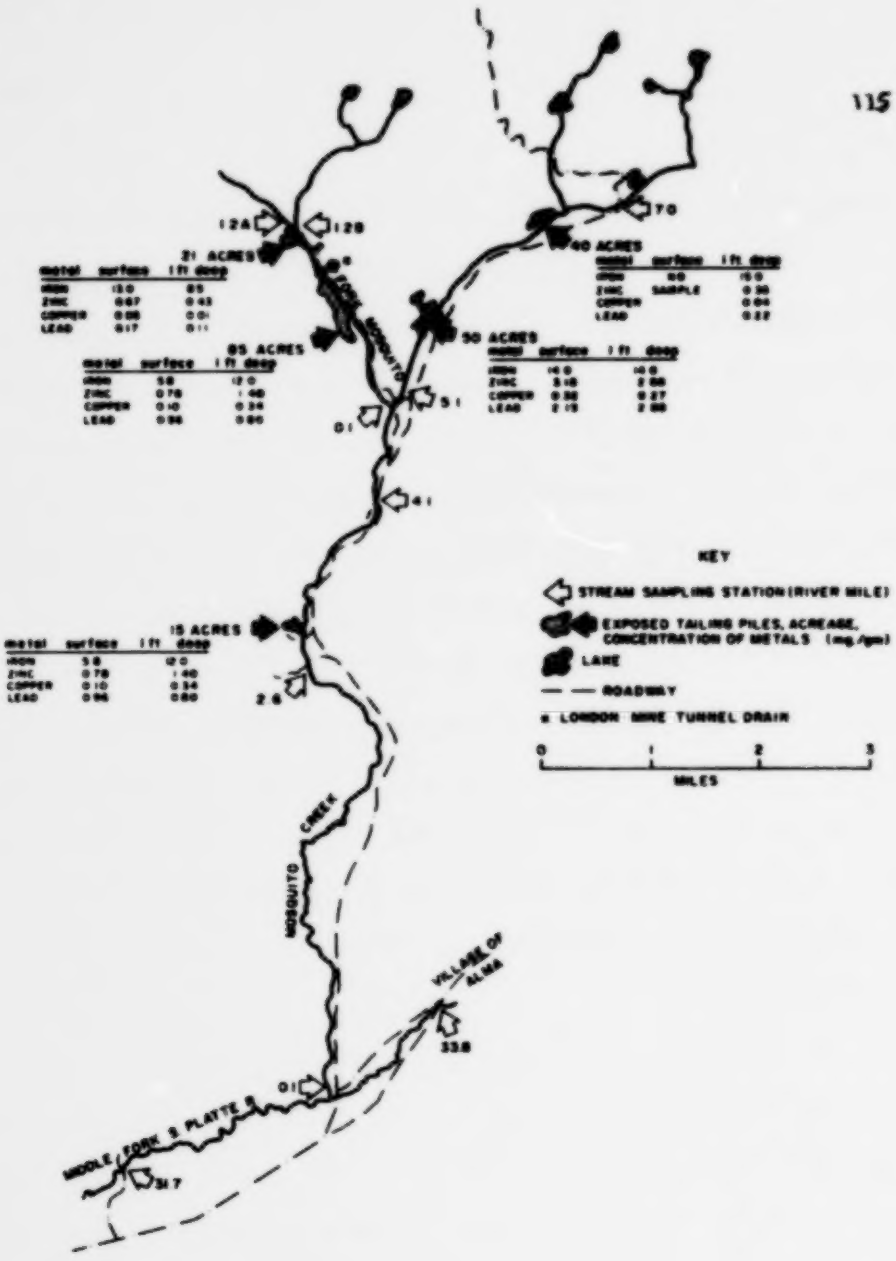
12A
12B
21 ACRES
metal surface 1 ft deep
IRON 13.0 8.5
ZINC 0.07 0.43
COPPER 0.08 0.01
LEAD 0.17 0.11
85 ACRES
metal surface 1 ft deep
IRON 5.8 12.0
ZINC 0.78 1.40
COPPER 0.10 0.34
LEAD 0.96 0.80
FORK MOSQUITO
7.0
60 ACRES
metal surface 1 ft deep
IRON NO 15.0
ZINC SAMPLE 0.30
COPPER 0.04
LEAD 0.22
50 ACRES
metal surface 1 ft deep
IRON 14.0 14.0
ZINC 3.10 2.88
COPPER 0.32 0.27
LEAD 2.15 2.88
5.1
0.1
4.1
15 ACRES
metal surface 1 ft deep
IRON 5.8 12.0
ZINC 0.78 1.40
COPPER 0.10 0.34
LEAD 0.96 0.80
2.6
KEY
STREAM SAMPLING STATION (RIVER MILE)
EXPOSED TAILING PILES, ACREAGE, CONCENTRATION OF METALS (mg./gm)
LAKE
ROADWAY
* LONDON MINE TUNNEL DRAIN
0
1
2
3
MILES
MOSQUITO CREEK
VILLAGE OF ALMA
33.8
0.1
MIDDLE FORK S PLATTE R
31.7

FIGURE 47. MOSQUITO CREEK BASIN, EXPOSED TAILING PILES, AND METAL CONCENTRATIONS IN TAILINGS.

deposits of precious and other mineral ores that have been extensively mined. Internal drainage in London Mountain is collected in the widespread and interlaced tunnel systems and most of it appears to flow southward emerging at the entrance to the South London Tunnel with discharge to the South Fork of Mosquito Creek. Small quantities of additional mine drainage are discharged from other shafts on London Mountain, south of Mosquito Creek on the north flank of Pennsylvania Mountain, and north of the creek from Loveland Mountain.

Mining in the Mosquito Creek region began in the 1860's. Since the initial strikes production has fluctuated with peaks occurring during the periods 1870-1880, 1905-1910, and the 1930's. During and since World War II, mining has been nearly dormant in the Basin, the only activity being exporation and maintenance of some tunnels in anticipation of economic changes that would again make production feasible.

Compared to most mine drainage waters, the water drained from the South London Mine Tunnel is atypical because it is slightly alkaline (pH, 7.1-7.5; alkalinity, 100 mg/l). The most significant heavy metal discharged in the drain water is zinc, which varied in concentration from 4.3 to 4.8 mg/l, a concentration that was about nine times the toxicity threshold for fish. Iron concentrations fluctuated, the minimum (0.4 mg/l) would not be toxic to fish, but the maximum observed (6.3 mg/l) would be decidedly toxic. Copper concentrations in the drain water averaged 0.10 mg/1. Copper, considered by itself, would not be expected to affect aquatic animal life, but these concentrations could be at the threshold of affecting algae.

Exploratory mining conducted via the South London Tunnel entrance may have been the cause of fluctuations in the observed concentrations of heavy metals. Following a week of mining activity, iron concentrations had risen to 6.8 mg/1 on Saturday (July 30); the lowest concentration of iron (0.4 mg/1) was found on a Sunday morning (July 31).

Prior to World War II there were milling and concentrating operations located at several sites in the Basin. These operations left large deposits of tailings. The South Fork of Mosquito Creek has maintained a channel eroded into extensive deposits that nearly cover 1 mile of the downstream-most reach of the valley. Figure 47 illustrates the locations of the five major exposed tailing deposits that cover a total of 211 acres as measured from aerial photographs.

During each rainfall, runoff from the exposed deposits erodes the metal-bearing tailings into the waterways. These deposits contain significant quantities of iron, zinc, copper, and lead that play havoc with the biota in the waterways. In addition, the rock flour discharged to the streams increases the quantity of suspended solids and the turbidity values in the water, resulting in reduced penetration of light that is required for photosynthesis by the bottom attached algae. These tailings also settle to the stream bottoms where they smother existing organisms, cover up stable stream bottom substrates with blankets of shifting uninhabitable material, and fill the instices in gravels and between rocks that serve as habitats for animals and the incubation of trout eggs. The milky appearance of the waters reduces aesthetic values.

Damage to the primary food-producing algae is very significant. The quantity of chlorophyll in the algal communities was drastically reduced (Figure 48), and the number of algal cells was reduced approximately 90 percent.

The mining wastes' effect on bottom animals was a drastic reduction in the number of animals inhabiting the waterways (Figure 49). The number of animals increased midway downstream (Station 2.6) but the increase in numbers was the result of flourishing populations of larvae of two kinds of pestiferous black flies that made up 85 percent of the total individual animals found. Swift currents at this station kept sediments from accumulating on the surfaces of the rock rubble substrates, thus allowing these animals attachment sites; and the larvae of some species of black flies are relatively tolerant of heavy metals.

The fish populations were adversely affected by the pollution from mining wastes. The number of fish were reduced as much as 90

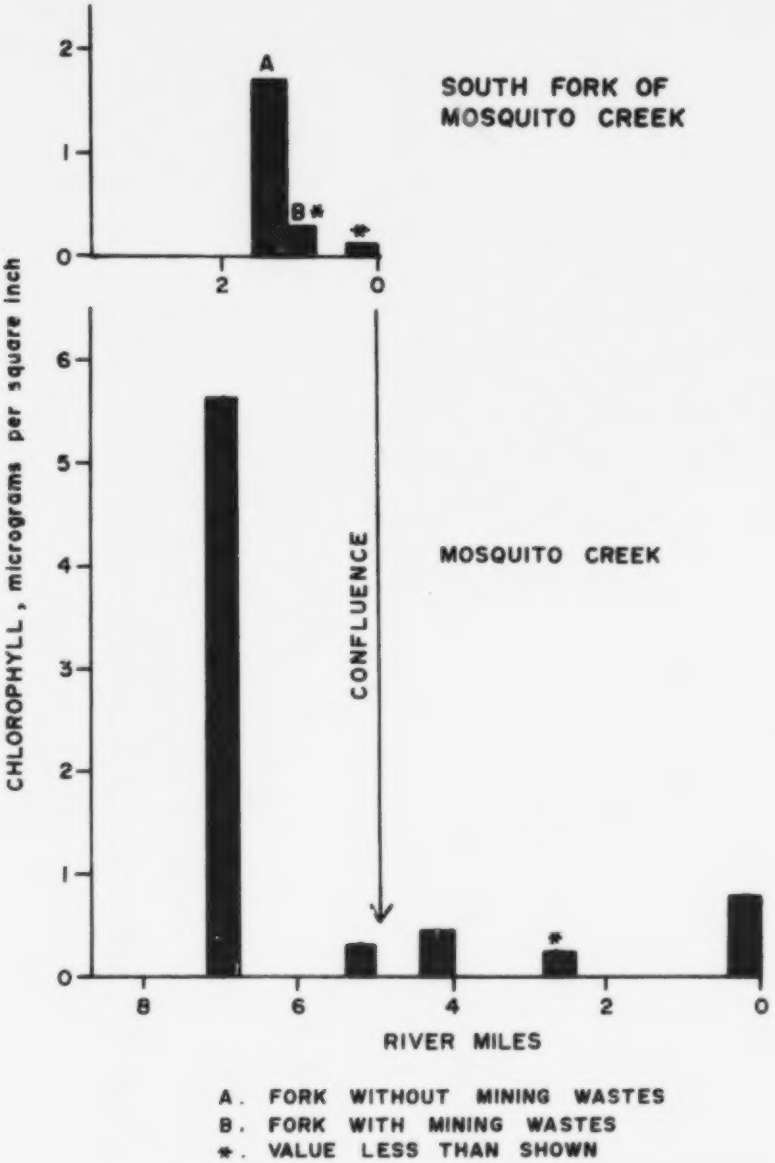

FIGURE 48. EFFECT OF MINING WASTES ON BOTTOM ATTACHED ALGAE, MOSQUITO CREEK BASIN, COLORADO, JULY-AUGUST 1966.

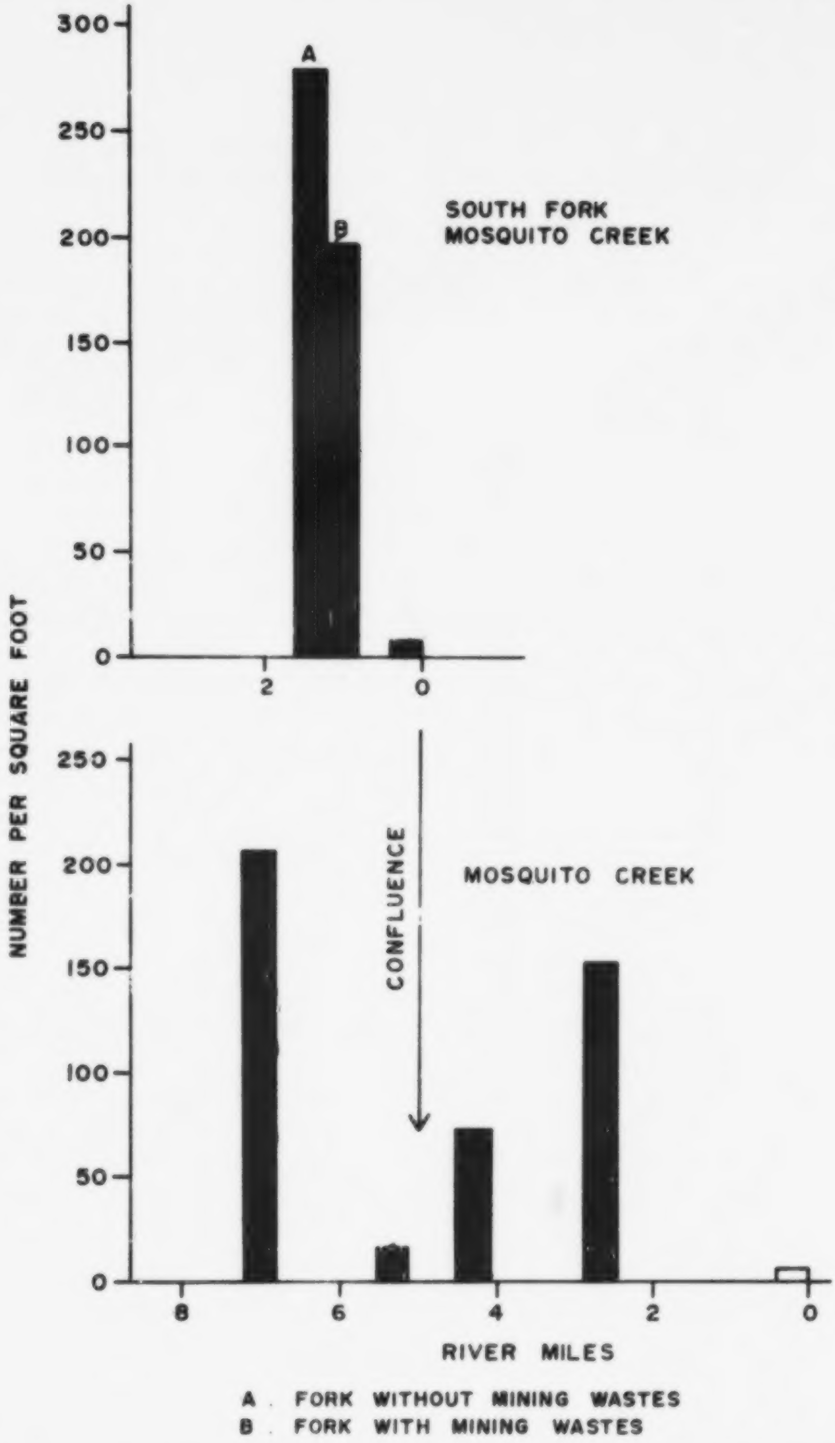

FIGURE 49. EFFECT OF MINING WASTES ON BOTTOM ANIMALS, MOSQUITO CREEK BASIN, COLORADO, JULY-AUGUST 1966.

percent in the affected reaches when compared to the upstream clean water area (Figure 50). The toxicity threshold was also exceeded in most of the stream reach studied. Heavy metals contributing significant proportions to the toxicity were iron, lead, and zinc.

Damage to the Basin's aquatic life is attributable to two major sources: 1) the drainage water discharged from the South London Tunnel, and 2) the exposed tailings piles.

After entering the mainstream of Mosquito Creek at river mile 5.0, the materials discharged via the South London Tunnel are diluted to approximately 5 percent of the initial concentration in the drain water. Maximum concentrations observed in the drain water, estimated concentrations after dilution, and observed maximum concentration in the mainstream are as follows:

	Maximum Observed Concentrations, mg/1		
Heavy Metal	South London Mine Drain	Estimated After Dilution (20:1)	Observed in Mainstream (Station 4.1)
Iron	6.8	0.3	2.6
Zinc	4.5	0.2	0.48
Lead	0.04	Trace	0.10

From these data, it is obvious that other pollution sources contribute much greater quantities of polluting iron and lead than from the mine drain. Zinc discharged from the drain is relatively more significant than the other metals. The concentration of zinc in the drain ranges from 4.3 to 4.8 mg/1 (mean 4.5) and on the average, after

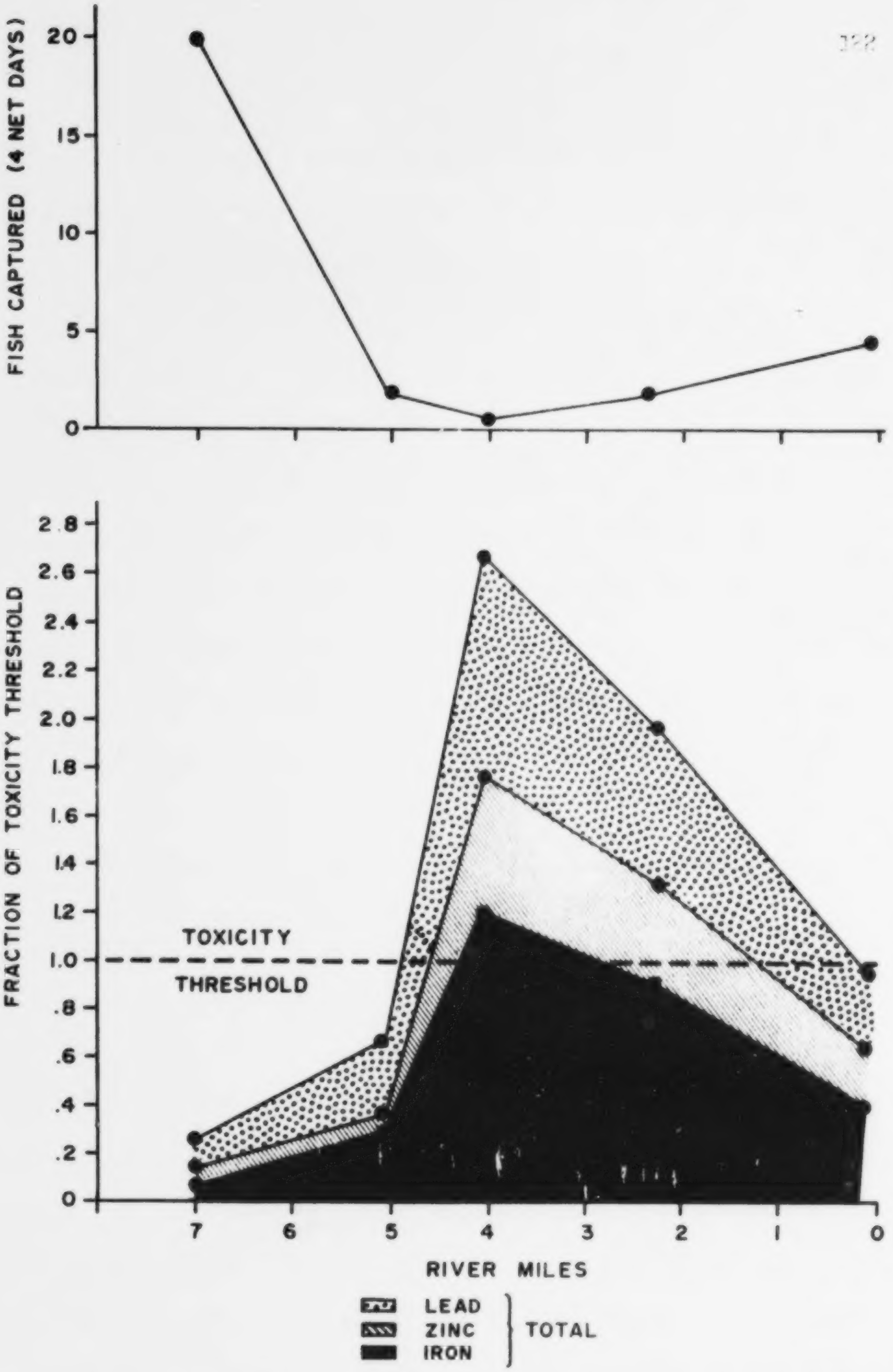

FIGURE 50. FISH AND HEAVY METAL TOXICITY IN MOSQUITO CREEK, COLORADO, JULY-AUGUST 1966.

dilution contributed about 40 percent of the zinc to the concentrations observed at Station 4.1 on the mainstream. The quantity of zinc discharged by the drain should be reduced by at least 75 percent which would reduce the zinc fraction of the toxicity threshold to approximately 0.3 in the mainstream. If the method selected to reduce zinc also removes a portion of the iron this would provide an additional benefit.

A highly significant portion of the heavy metal pollutants was derived from the exposed tailings piles. During and after rain showers surface runoff eroded significant quantities of metal bearing tailings into the waterways. This was especially evident in the watershed of the South Fork of Mosquito Creek where 50 percent of the total Basin's area of exposed tailings piles were found. After brief showers on August 1, the concentrations of polluting materials relatable to a tailings pile origin were significantly higher than the average. Examples of these differences are as follows:

	Concentration, mg/l		
Material	Minimum Value	Average Value	August 1
Total suspended solids	9.6	127.0	556.0
Turbidity (units)	27.5	30.5*	190.0
Iron	1.4	3.7	11.0
Zinc	0.62	0.9	1.93
Copper	< 0.02	< 0.06	0.21
Lead	0.2	1.00	1.80

* Median Value

Erosion of tailings into the waterway undoubtedly does more damage than all the tunnel and shaft drains in the Basin. In addition to the toxic metals discharged to the waterway, these tailings are also the principal source of rock flour that clouds the waters and settles to the bottom, thus destroying the habitat that is the primary basis for aquatic life propagation.

The problem of tailing pile erosion will have to be solved. It is highly unlikely that any valuable use can be made of these tailings in the foreseeable future. Moving of the tailings to other less objectionable sites would be very difficult because of the volume of material to handle and distances required to get them to a site where pollutional affects would be minimal. The most readily available solution towards solving the problem would be burial of the tailing piles with rock, soil, and vegetation, thereby stabilizing the surface and eliminating erosion.

Gravel and Sand

The use of alluvial gravels and sands for construction is a major industry in the South Platte Basin. The value of these materials is in excess of 2.5 million dollars (1). There are many sites in the Basin where gravels and sands are recovered from deposits and are washed and hydraulically sorted.

The water supply systems used by the various companies play a vital role in whether or not a company is a polluter. Some companies use closed systems in which the waters are recycled, thereby preventing pollution because wastewaters are not discharged to the waterways. Other systems involve withdrawal of water from the waterways, and after washing operations, the dirt-bearing waters are discharged back to the streams. These latter systems seriously pollute waterways.

The effects of a typical system discharging its dirty wastewaters was selected and studied in August 1966. The selected site was the Hall Sand and Gravel Company, Highway 75, Blakeland, which discharged its used wash waters directly to the South Platte River. The quantity of suspended solids discharged varied from 16 to 36 tons per day, averaging 28 tons. These solids affected a significant increase in the turbidity and concentrations of suspended solids in the waters of the South Platte River (Figure 51).

Suspended solids have an adverse effect on the aquatic life in a stream. They reduce the light available for photosynthesis, settle to the stream's bottom where they change the nature of the bottom to shifting silts and sands, and bury and smother incubating fish eggs. The net end product of these effects is a drastically reduced fish population (Figure 52).

Abatement of pollution from gravel and sand washeries will be required throughout the South Platte Basin before degenerate habitats for aquatic life can be restored. Abatement of this

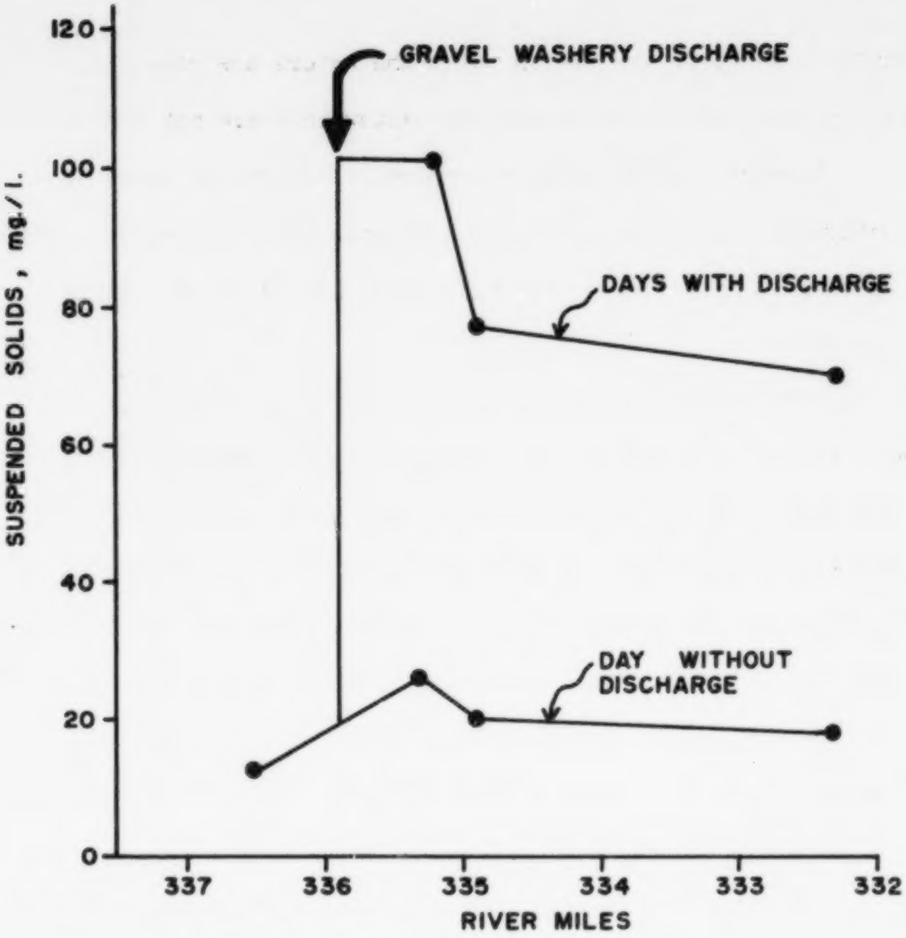

FIGURE 51. EFFECT OF DISCHARGED GRAVEL WASHING WATERS ON SUSPENDED SOLIDS, SOUTH PLATTE RIVER, COLORADO, AUGUST 1966.

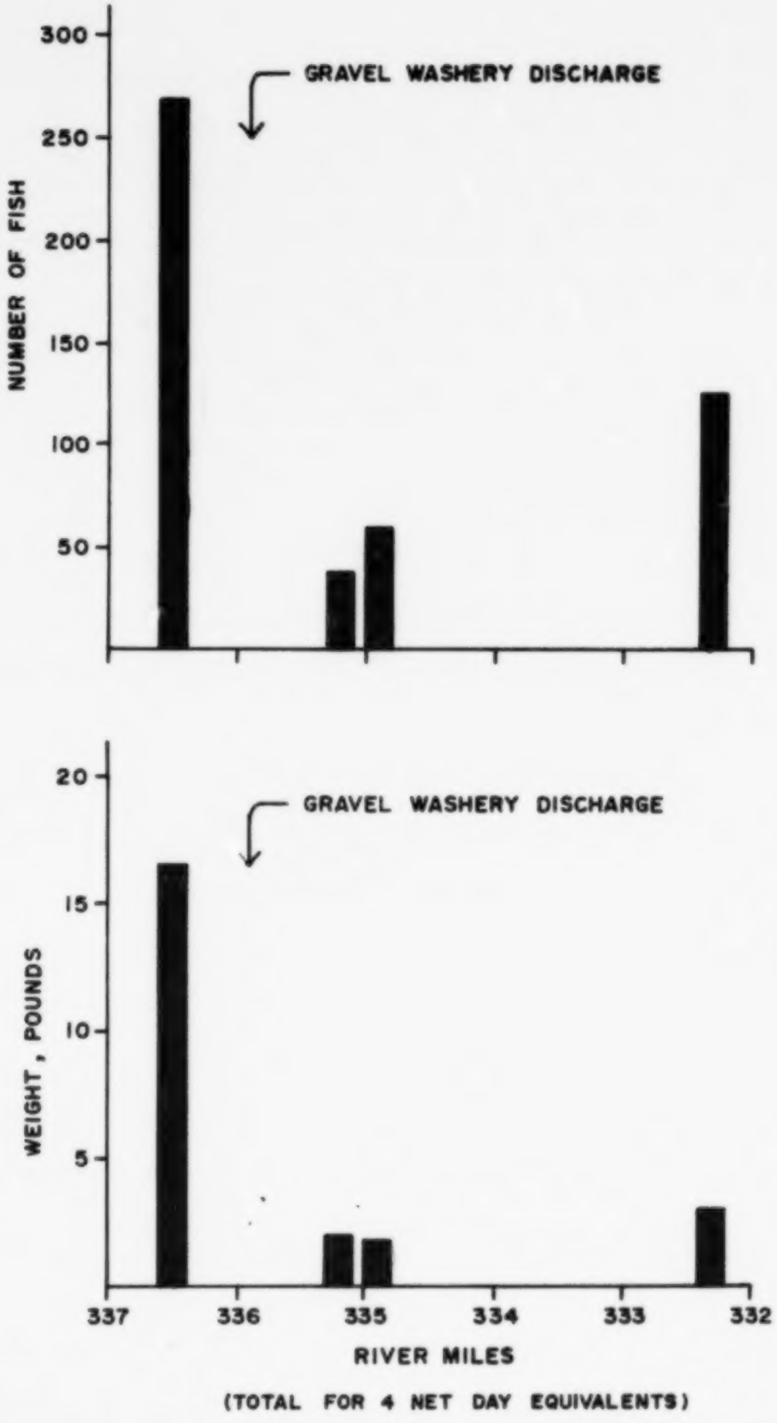

FIGURE 52. EFFECT OF DISCHARGED GRAVEL WASHING WATERS ON FISH POPULATIONS, SOUTH PLATTE RIVER, COLORADO, AUGUST 1966.

pollution will probably be easier than for other types of waste waters. Simple discharge to the borrow pits available at the washery, or to easily constructed lagoons is a feasible method. During detention in these ponds the suspended dirt settles from the water and the cleared water can then be reused by the washery, or seep through porous bottom and bank soils filtering itself further while percolating back to a stream. Clear water overflowing from the ponds can be returned to the stream.

Miscellaneous

In addition to the specific causes of pollution already discussed, there are several other industries that are polluters. These have not been subjected to special or specific studies of their effects on aquatic life because in many instances their pollutants enter already grossly polluted waters and the effects of these wastes on the already decimated aquatic life is not measurable as a separate entity. In most instances, effects from these sources have been included in the category of MUNICIPAL WASTES. It is recognized that with abatement of pollution through the cleansing of waste waters originating via existing municipal sewage systems, many separately discharged industrial wastes will then become the major source of pollutants to the waterway.

Food Processing

There are many slaughterhouses and vegetable canneries located at various sites throughout the Basin. The waste waters from these industries may be discharged without treatment or with inadequate treatment to the waterways. The effects of these wastes are similar to those of any other decomposable organic material.

The Kuner-Empson cannery at Longmont is one example of a food processor that pollutes the waters. Waste waters discharged to St. Vrain Creek by this company contain organic decomposable materials equivalent in strength to the untreated sewage from a city of 2,600 persons (11). As the company changes its operations to accommodate the seasonally available produce the nature, character, and strength of its waste waters vary. For example, during the processing of garden beets, St. Vrain Creek may run blood red in color, and pieces and slices of wasted beet material can be found scattered over the stream bottom and along its banks for several miles downstream from the company's waste water discharge.

Cattle Feed-Lots

Many cattle feed lots are located at widely scattered sites throughout the plains region of the Basin. Many of these feed-lots have been placed along the banks of streams for one or more probable reasons: 1) The stream's non-tillable flood-plain banks were not being used for other forms of agriculture. 2) The watercourse served as a convenient watering point for the herd. 3) The site was convenient to the cattle tending men who live on the farms or in the communities of the "green belt" bordering the waterways. Many of the physical features of the feed-lots violate recommended practices of land, water, and animal management (Figure 53).

Cattle with access to extensive reaches of a stream can directly muddy the waters, and destroy the banks of the waterway by the action of trampling the banks down and with destruction of stabilizing vegetation, both resulting in extensive stream bank erosion. In most regions of the country it is recommended that cattle be fenced from the stream banks allowing them only limited and managed access to watering points.

The extremely dense cattle populations in feed-lots results in the accumulation of thick deposits of manure. When feed-lots border the streams, or if drainage systems lead directly to the streams, runoff from precipitation can wash large quantities of manure into the waterways. In the waterways these manures and urine act similarly to the organic wastes in domestic sewage--they settle to form sludge beds and decompose, thereby altering the waterway's chemistry, and contribute fertilizing nutrients.

Cattle feed-lots need to be relocated away from their present stream-side sites. Large acreages of uplands located away from watercourses are available and could be used effectively for this

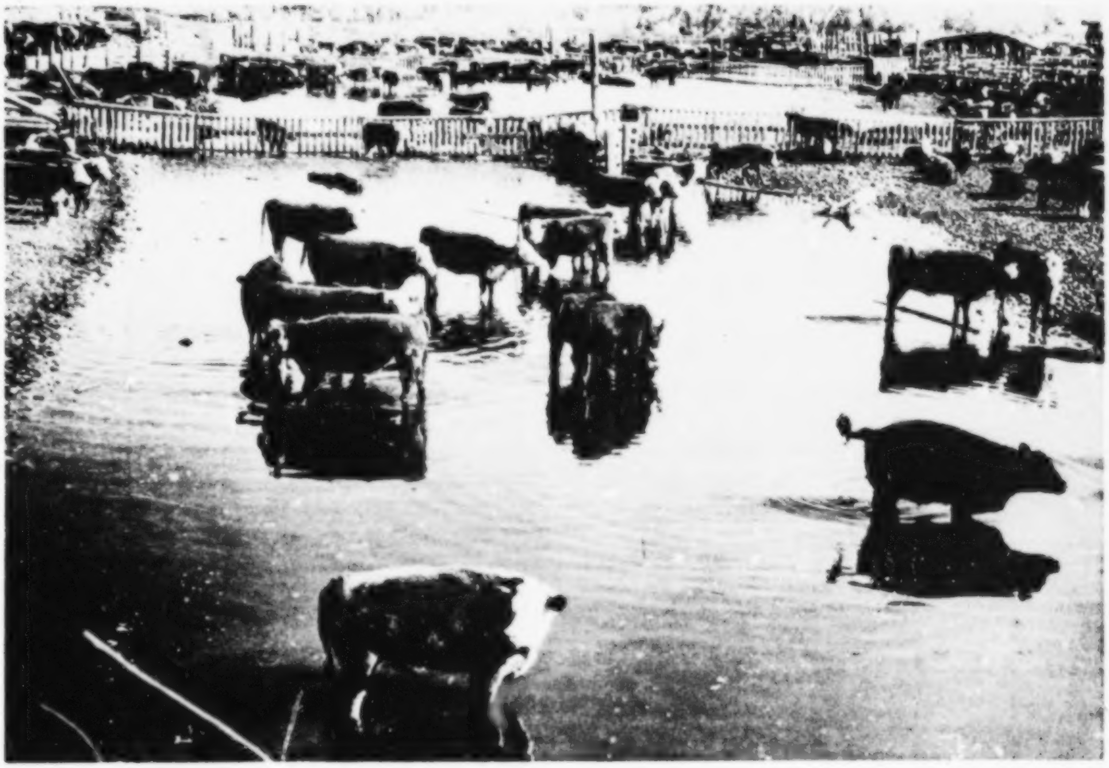

FIGURE 53

CATTLE FEED-LOT POLLUTING ST. VRAIN CREEK NEAR LONGMONT, COLORADO purpose. In addition to preventing water pollution, subsidiary benefits from such a move could be obtained. Location away from population centers would reduce the problem of odors from the manures. Use of ground water as a water supply, and land disposal of wastewaters for seepage and evaporation would reduce the risk of herd-to-herd disease transmission that today is possible by using surface water supplies which frequently are contaminated by wastes from upstream feed-lots.

Irrigation Return Waters

During the biological studies conducted in the South Platte Basin, adverse effects on aquatic life that could be specifically attributed to irrigation waters were not detected. The quantity of salts discharged to the waterways apparently are not significant to raise salinities (dissolved solids) to levels that would be detrimental to the fresh water fauna and flora. Increased future water use and reuse may raise these salt concentrations to levels that could prove detrimental. In a mixture of salts where the relative concentrations of the various salts is equivalent to that found in natural uncontaminated waters, concentrations up to 2,000 mg/l (34) would not be expected to prove directly detrimental to fish. Aquatic insects are more sensitive than fish and some of the species that serve as fish food may be adversely affected at concentrations of salt near 1,000 mg/l. If certain salts, such as sulfides and bromides, contribute abnormally high proportions of the total dissolved materials, adverse effects may be expected at lower total dissolved solids concentrations.

Nutrients leached from fertile agricultural lands may prove to be stimulators of over-production of undesirable aquatic growths. At the times of these surveys, evidence of irrigation-return nutrients in the streams were not obvious. This may be because of relatively high quantities of nutrients from other waste water sources already present in the streams.

Thermal pollution, or an increase in water temperature, through the addition of warm irrigation return waters to the streams was not observed. In fact, stream temperatures in reaches bordered by farming activities were well within acceptable limits for aquatic life.

MEASURES FOR IMPROVING AQUATIC LIFE RESOURCES

A major problem in the management of aquatic life resources in the South Platte Basin is the occasional total diversion of stream flows for irrigation or other uses. It is obvious that to perpetuate aquatic life a minimum quantity of water must remain in a waterway to sustain life until larger quantities are again available. Not only is a minimum required for the propagation of desirable forms of aquatic life, it is also required to prevent the over-production of nuisance organisms when the stream flows are principally wastewater

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effluents even though sometimes treated to the highest degree possible by commonly used treatment methods. For these reasons, the South Platte River Basin Project has requested that provisions be made for:

> "A. Minimum streamflows of 25 cfs (to) be maintained on the mainstem South Platte River throughout the entire year and at all locations, from upstream of Littleton down to the Colorado-Nebraska Stateline.
>
> B. Minimum streamflows of 15 cfs (to) be maintained on St. Vrain Creek from above Longmont downstream, on the Big Thompson River from above Loveland downstream and on the Cache La Poudre River from above Windsor downstream, throughout the entire year and at all locations within the designated areas." (12).

These low flows are the minimum required in the immediate future. If population and industrial expansion continues in the Basin, at later dates even larger volumes will be required.

Minimum stream flows in volumes larger than those requested by the Federal Water Pollution Control Administration may provide still additional benefits in the Basin. The Bureau of Sport Fisheries and Wildlife has proposed that provision be made in the planning and future operation of reservoirs upstream from Denver to provide for minimum streamflows of 60 cubic feet per second. "Chatfield Reservoir offers broad opportunities for improvement in stream fish habitat requirements. Exchanges of reservoir storage with the proposed upstream Two Forks Reservoir or prospective downstream reservoirs, to effect continual releases, could result in considerable benefit to at least 65 miles of the South Platte River fishery. It is our understanding that a minimum release of 60 second-feet could be provided without increased construction costs. Provision for a minimum instantaneous release from Chatfield Reservoir of 60 second-feet would improve fish habitat for trout as well as warmwater fishes." (37).

Discussions have arisen (12, 38) as to the type of fisheries that could be developed in the South Platte River when the waters are again cleaned. Available data from the South Platte River Basin Project and the U. S. Geological Survey indicate that the waters temperatures would be adequate for trout at least downstream to the City of Greeley (Figure 54). The water temperatures may rise in the future because of some use change such as thermal loads from cooling water discharges or solar warming of waters stored in proposed reservoirs, but a warm water fishery would also be an asset to the dense population centers bordering this reach of the river.

The proposed Narrows Reservoir near Fort Morgan is another potential source of water for low flow augmentation. The Bureau of Sport Fisheries and Wildlife has requested "A minimum instantaneous

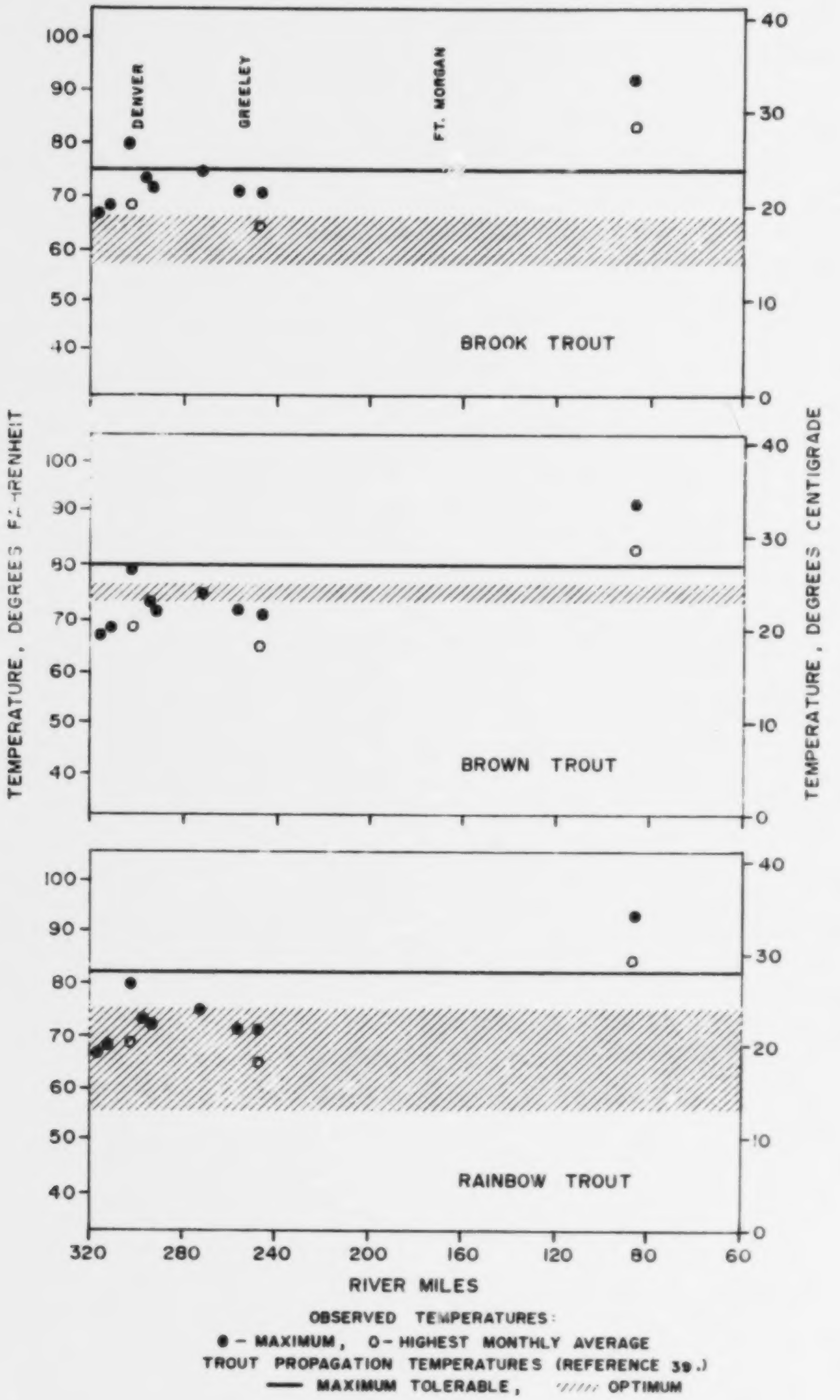

FIGURE 54 TEMPERATURES OF SOUTH PLATTE RIVER WATERS IN RELATION TO MAXIMUM TOLERABLE AND OPTIMUM TEMPERATURES FOR BROOK, BROWN, AND

flow of 50 second-feet be maintained in the South Platte River below Narrows Dam" (30). This request for water for fisheries and wildlife management purposes has been concurred with by the Commission of the Colorado Department of Game, Fish and Parks. The Narrows Dam is designed to increase the volume of water available for downstream use by holding and storing floodwater. Use of a portion of this stored water for low flow augmentation would negate the need to purchase existing water appropriations, but provisions will have to be made to reserve a fraction of this volume from future sale or appropriation.

To maintain a low flow minimum in the entire South Platte River of 25 cubic feet per second between 10,000 to 18,000 acre feet per annum of water will be required (12). The proposed Chatfield Dam (and other upstream existing and proposed dams) could provide storage volume for supplementing flows in the 130-mile reach upstream from the Narrows Dam. This is about one-half the reach of stream that requires low flow augmentation, thus 9,000 acre feet would be required and, if this were stored in the Chatfield Dam pool, the flood control capacity would be reduced about 4 percent. The remaining required volume of water for the 120-mile reach from the Narrows Dam to the Colorado-Nebraska State-line may be stored in the Narrows Reservoir and would occupy about 0.2 percent of the joint use pool volume. These figures do not consider low flow augmentation of 15 cubic feet per second requested for St. Vrain Creek, the Big Thompson River, and the Cache la Poudre River.

A portion of the low flow augmentation could be achieved by using existing waters in the system with closer programming and synchronizing of water diversions. It is possible to witness total diversion of the flow for a few days at a given point, followed with total bypass on subsequent days to a downstream diversion point. Coordination to provide simultaneous diversion at reduced rates at both points during this time would aid in maintaining minimum flows in stream reaches between diversion sites.

The usable quantity of surface water in the South Platte Basin could be increased effectively by modernization of water distribution systems. As much as 50 percent of the volume of water initially available may be lost in conveying waters to the irrigation fields. Projections for the supply and distribution of water from the proposed Narrows Reservoir have been "...adjusted to reflect 38 percent transportation losses of water from the reservoir to the farm." (30). In some distribution systems as much as half of the water volume lost can be prevented by changes instituted in canal and ditch systems.

The State of Colorado could purchase water rights and retain the water and its title in the public waterways for the public's benefit. Any changes in water use "...are possible only by modification of the prevailing patterns of water management and use." (38). Providing for and instituting changes in water use is a function of the State of Colorado.

Because of future population and industrial growth and with no further development or use of technological advancements in waste treatment, the quantity of wastes discharged to the South Platte will increase after the projected minimum levels are achieved. This is because about 10 percent of the decomposable material is not recoverable by the facilities planned for, or in operation. Thus, with time and no future changes to improve treatment facilities one may expect a time in the future when water quality conditions again become unsatisfactory in reaches downstream from Denver. It may then be feasible to alter the treated waste effluents by diverting them into Barr Lake and Horse Creek Reservoirs. The advantages of such a consideration are:

1. Prevention of contamination of clean waters flowing in the South Platte River.
2. Confinement of the polluted waters in manageable and controlled volumes where continued treatment through natural time-related processes can be achieved, along with supplemental treatment such as mechanical or chemical oxygenation, odor, and vector

control, ice-cover control to maintain atmospheric aeration of waters, etc.

3. After restoration of quality to waters, excess accumulated waters in the reservoir may then be routed back to the Basin's waterways for reuse and without risk of damage to waters over a large area.

ACKNOWLEDGMENTS

The following Federal Water Pollution Control Administration personnel have been associated with aspects of the biological studies presented in this report.

George Brown, Biological Science Aide,
Technical Advisory and Investigations Branch
December 1964 through December 1966.

Kenneth Burlingame, Biologist,
South Platte River Basin Project
July 1963 through August 1964.

David Clough, Sanitary Engineer,
South Platte River Basin Project
April through August 1964.

Mark Hibpshman, Engineering Aide,
South Platte River Basin Project
October 1964.

Frank Kanatani, Biological Science Aide,
South Platte River Basin Project
June 1964 through August 1964.

Lowell Keup, Aquatic Biologist,
Technical Advisory and Investigations Branch
July 1963 through June 1967.

Stephen Lewis, Biological Science Aide,
South Platte River Basin Project
June 1964 through August 1964.

Kenneth M. Mackenthun, Aquatic Biologist,
Technical Advisory and Investigations Branch
May 1964.

Loys Parrish, Aquatic Biologist,
Technical Advisory & Investigations Branch
September 1966 through March 1967.

R. Keith Stewart, Aquatic Biologist,
Technical Advisory and Investigations Branch
September 1964.

Mr. James L. Richard and Dr. Fred Harmston, Communicable Disease Center, Public Health Service, Greeley, Colorado, and the South Platte River Basin Project, cooperatively developed the report Significant Vector Problems in the South Platte River Basin (*14). A portion of the material in this report dealing with disease vectors has been obtained from this report.

Chemical analyses reported herein were performed by the Laboratory Section of the South Platte River Basin Project or by the Biological and Chemical Section of the Technical Advisory and Investigations Branch, Cincinnati, Ohio.

Flow data were obtained from records of the U. S. Geological Survey or by measurements made by the South Platte River Basin Project.

Dr. William M. Ingram, Chief, Biological and Chemical Section, Technical Advisory and Investigations Branch, Cincinnati, Ohio, has reviewed and critically analyzed the biological activities herein.

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* U. S. Department of Health, Education, and Welfare. Public Health Service, Region VIII, Denver, Colorado, March 1965, ii + 22 pp. and Figures.

Lowell Keup, Aquatic Biologist, Technical Advisory and Invesigations Branch, Cincinnati, Ohio, has coordinated and provided continuity in the biological activities and prepared this report.

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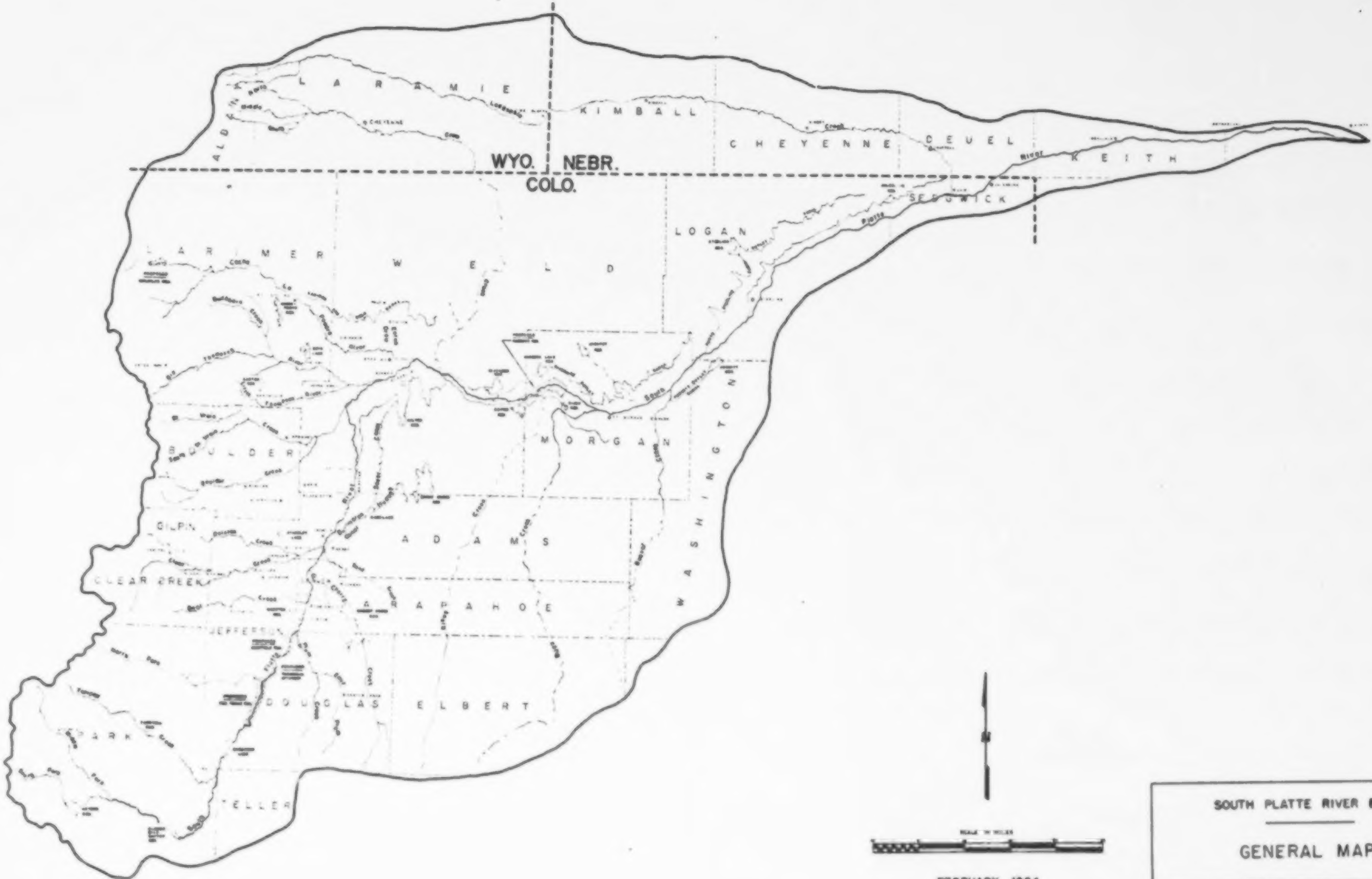
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SEDGWICK
LOGAN
LARIMER
WELD
MORGAN
WASHINGTON
BOULDER
GILPIN
ADAMS
CLEAR CREEK
ARAPAHOE
JEFFERSON
DOUGLAS
ELBERT
PARK
TELLER
South Platte River
SCALE IN MILES

FEBRUARY 1964
REVISED MARCH [illegible]
REVISED AUGUST [illegible]

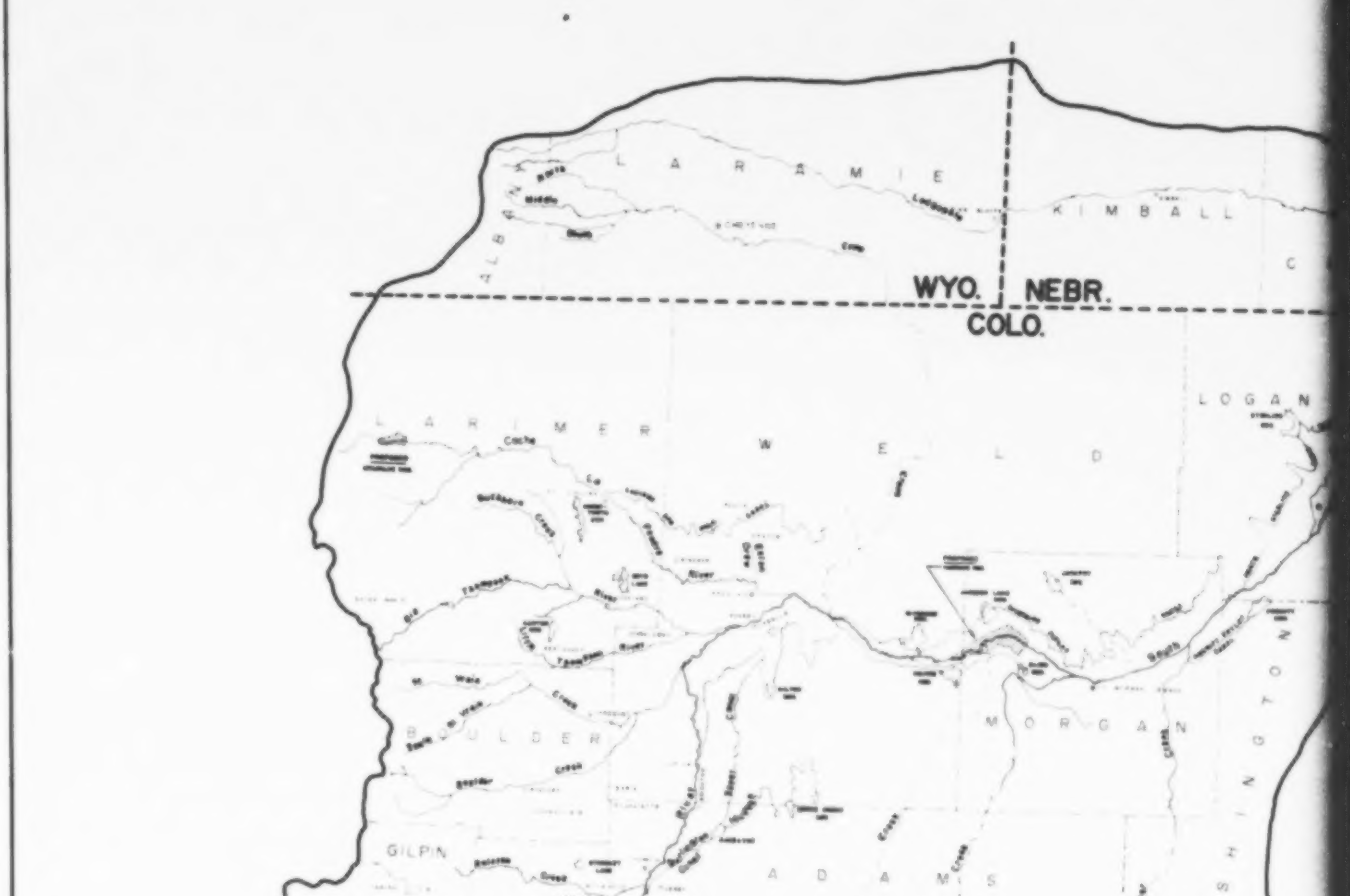
SOUTH PLATTE RIVER BASIN

GENERAL MAP

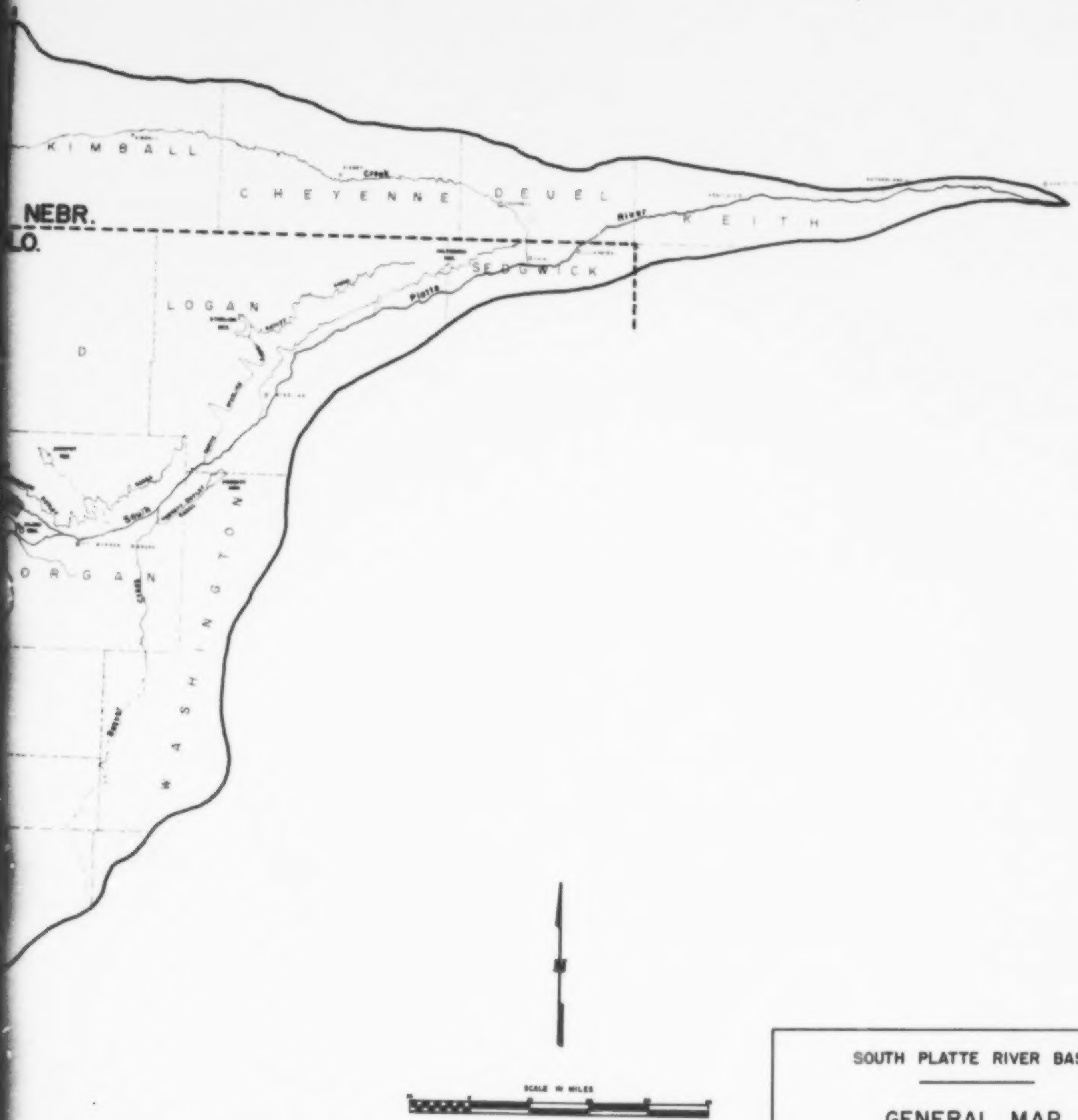
U.S. DEPARTMENT OF THE INTERIOR
Federal Water Pollution Control Administration
Denver, Colorado

FIGURE 1

A


WYO.
NEBR.
COLO.
LARAMIE
ALBANY
KIMBALL
LOGAN
LARIMER
WELD
MORGAN
BOULDER
GILPIN
ADAMS
CLEAR CREEK
ARAPAHOE
JEFFERSON
WASHINGTON
DOUGLAS
ELBERT
PARK
TELLER
Lodgepole
Crow
Cache
Buckhorn Creek
Big Thompson
Little Thompson River
St. Vrain Creek
Boulder Creek
Clear Creek
Bear Creek
Cherry Creek
Kiowa Creek
Bijou Creek
Beaver
Platte
Plum Creek
East Plum Creek
North Fork
Tarryall Creek
South Fork
South Platte River

B


KIMBALL
Creek
CHEYENNE
DEUEL
NEBR.
LO.
River
KEITH
SEDGWICK
Platte
LOGAN
D
South
ORGAN
WASHINGTON
N
SCALE IN MILES

FEBRUARY 1964
REVISED MARCH 1966
REVISED AUGUST 1966

SOUTH PLATTE RIVER BASIN

GENERAL MAP

U.S. DEPARTMENT OF THE INTERIOR
Federal Water Pollution Control Administration
Denver, Colorado

150

FIGURE 1